kristi maritime

CA1
DTC800-
90
D21

41.D

MM

CA1
DTC800-
90
D21

451956

41.D

TP# 10553E
Design and Application of Strakes on a Canadian Coast Guard Ship

Prepared for
Transportation Development Centre
Policy and Coordination Group
Transport Canada

September 1990

by

Mr. John E. Carter

Kristi Maritime Inc.
P.O. Box 1153
Pointe Claire Village, Quebec
H9S 4H9

Library and Information Centre / Centre de Documentation (GSLA)
RECEIVED - REÇU LE
OCT 17 1990
Transport Canada / Transports Canada

451956

DDN 4418939

91-02499/

Disclaimer

The contents of this report reflect the views of the author and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

Un sommaire en francais de ce rapport est inclus avant la Table des matieres.

Project Team

For Kristi Maritime, Naval Architects, Inc.

Mr. John E. Carter

For Donald Carter and Associates (Math Model)

Dr. Donald Carter

Acknowledgements

The author wishes to acknowledge the contributions and guidance of M. J. Laframboise and Mr. M. Stenson, Transportation Development Centre, Policy and Coordination Group, Transport Canada, and M. Daniel Gauvin, Canadian Coast Guard, Transport Canada, throughout the execution of the project.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.	2. Project No.	3. Recipient's Catalogue No.
TP 10553E	7238	

4. Title and Subtitle

Design and Application of Strakes on a Canadian Coast Guard Ship

5. Publication Date

September 1990

6. Performing Organization Document No.

7. Author(s)

Mr. John E. Carter

8. Transport Canada File No.

D 1460-239-3

9. Performing Organization Name and Address

Kristi Maritime, Naval Architects Inc.
P.O. Box 1153, Pointe Claire Village
Quebec
H9S 4H9

10. DSS File No.

15SD.T8200-8-8558

11. DSS or Transport Canada Contract No.

T8200-8-8558/01-SD

12. Sponsoring Agency Name and Address

Transportation Development Centre (TDC)
200 René Lévesque Blvd. West
West Tower, Suite 601
Montreal, Quebec
H2Z 1X4

13. Type of Publication and Period Covered

Final Jan 89-Sept 90

14. Project Officer

M. J. Laframboise
Mr. M. Stenson

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

16. Abstract

This project examines the design and application of Strakes on the CCGS "Sir Wilfrid Laurier" with a view to verifying the reduction in level icebreaking resistance and comparing the full scale results with the predicted performance as per a math model developed by Dr. D. Carter.

The optimum number and location of the strakes at the design waterline was determined from the math model and from which design drawings and specifications were produced for manufacture and installation on the test ship.

Full-scale tests were carried out on the Saguenay River in February, 1990. Math model predictions for reduced icebreaking resistance of 15.3% and 11.5% at the two trial drafts cannot be verified from the present full-scale data due to doubt as to the actual ice flexural strength in the test area. From observations made during the trials it is concluded that the strakes would have been far more effective if located further forward and lower on the hull.

It is recommended that additional trials be carried out with the vessel at the original design draft and with the addition of two smaller strakes, one each side, lower and further forward of those existing. Furthermore it is recommended that a sister ship, without strakes, be tested in similar ice conditions to provide a 'real' baseline for comparison.

17. Key Words	18. Distribution Statement
Icebreaker, Strakes, Level Ice Resistance	Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	-	34	-

TDC/CDT 79-005
Rev 88

Canada

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada	2. N° de l'étude	3. N° de catalogue du destinataire
TP 10553E	7238	

4. Titre et sous-titre	5. Date de la publication
Design and Application of Strakes on a Canadian Coast Guard Ship	septembre 1990
	6. N° du document de l'organisme exécutant

7. Auteur(s)	8. N° de dossier — Transports Canada
Mr. John E. Carter	D 1460-239-3

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Kristi Maritime, Naval Architects Inc. P.O. Box 1153, Pointe Claire Village Québec H9S 4H9	15SD.T8200-8-8558
	11. N° de contrat — ASC ou Transports Canada
	T8200-8-8558/01-SD

12. Nom et adresse de l'organisme parrain	13. Genre de publication et période visée
Centre de développement des transports (CDT) 200 ouest, boul. René-Lévesque Tour ouest, suite 601 Montréal, (Quebec) H2Z 1X4	Final janv 89-sept 90
	14. Agent de projet M. J. Laframboise Mr. M. Stenson

15. Remarques additionnelles (Programmes de financement, titres de publications connexes, etc.)

16. Résumé

La recherche touchant la conception et la réalisation de stries devant être fixées à la proue du brise-glace Sir Wilfrid Laurier de la Garde côtière canadienne a été menée dans le but de mesurer la réduction de la résistance à la marche exercée par des glaces uniformes, et de comparer les résultats obtenus aux résultats théoriques tirés du modèle analytique de prévision élaboré par le Dr. D. Carter.

Ce modèle a permis de déterminer de façon optimale le nombre et la position des stries par rapport à la ligne de flottaison de calcul; il a permis en outre d'établir les dessins ainsi que les spécifications nécessaires à la fabrication de ces stries et à leur mise en place sur la proue du navire choisi pour les essais.

Ces derniers ont eu lieu en février 1990 dans le Saguenay. Les résultats des essais en mer ne permettent pas de vérifier ceux de la modélisation mathématique (réduction de la résistance à la marche de 15.3 et de 11.5 p. 100 à l'égard des deux tirants d'eau observés, respectivement) en raison surtout des incertitudes entourant la résistance à la rupture en flexion réelle des glaces dans le lieu des essais. Les observations faites de visu indiquent que l'action des stries aurait été plus efficace si ces dernières avaient été fixées un peu plus bas et un peu plus en avant sur la proue.

Il est donc proposé de mener d'autres essais en vraie grandeur durant lesquels le navire opérerait au tirant d'eau de calcul et serait équipé de deux stries supplémentaires plus petites placées au-dessous et à l'avant des stries existantes, et que des essais dans des conditions glacielles comparables soient menés à bord d'un navire-jumeau non équipé de stries, et qui servirait de témoin, les données fournies par ce dernier servant de base de comparaison et permettant de déterminer la réduction réelle dans la résistance à la marche.

17. Mots clés	18. Diffusion
Brise-glace, Résistance dans la glace, Stries	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
non classifiée	non classifiée	-	34	-

CDT/TDC 78-005 Rev 88

Canada

Summary

Kristi Maritime, Naval Architects, Inc. have carried out a study jointly commissioned by the Transportation Development Centre and Canadian Coast Guard following tests carried out at the Institute of Marine Dynamics by Dr.D.Carter and Associates published under TP# 9356E "Model Tests of the Louis S. St. Laurent original bow fitted with Strakes" to verify the gains predicted by model tests for the application of Strakes on a Canadian Coast Guard Ship.

The project objective was to evaluate in full scale the reduction of icebreaking resistance effected by the presence of strakes on the bow of the ship.

The vessel selected for full-scale trials, based on availability, was the CCGS "Sir Wilfred Laurier".

The work carried out during this project included math model analysis as applied to the test ship, structural design of the strake configuration, full-scale trials and analysis of results.

Math model analysis was carried out by Dr.D.Carter and Associates and showed that one pair of strakes (one port and one starboard) fitted at the shoulders of the vessel frames 138-148 at an angle of approximately 20 degrees gave the optimum performance considering both level icebreaking and existing structural arrangements in the vessel.

Structural details were developed using existing Canadian Arctic Shipping and Pollution Prevention Regulations and Lloyds Classification rules in addition to direct calculations based upon predicted pressures as per the math model, with final details being approved by both Lloyds and the Canadian Coast Guard (AMNB).

Strakes were fabricated and fitted at MIL Davie, Lauzon, Quebec, during a refit period October/November 1989 under the direction of CCG Laurentian Region.

As a result of discrepancies in the "as fitted" height of the Lower Flat on the vessel the angles of attack of the strakes were modified. The changes were small and not considered to have a major impact on the overall resistance of the vessel.

Full-scale trials were carried out in the Saguenay River 5-9th February 1990 under the direction of Fleet Technology Limited, Calgary.

Full-scale trial results have been compared with math model analysis using actual trial drafts. In addition full scale trial results of the CCGS "Anne Harvey" have also been compared with the math model to verify correlation.

The math model predictions for reduced icebreaking resistance of 15.3% and 11.5% at the two trial drafts as a result of the strake application cannot be verified from the present data principally due to doubt as to the actual flexural strength of the ice in the test area.

The apparent substantial reduction in performance over that originally predicted of 30% is attributed to the shallower immersion of the strakes due to 1) vessel not being operated at full design draft of 6.0m and 2) permanent induced stern trim during trials.

Furthermore, observations during the trial program indicated that the strakes would have been far more effective if lowered and located further forward along the bow.

It is, therefore, recommended that further trials be carried out in which the vessel is run at the design draft with the addition of two smaller strakes fitted at the point of observed crushing lower and forward of the "as fitted" strakes. In addition, ice trials of a sister ship, without strakes, should be carried out in similar ice conditions to provide a baseline against which any actual reduction in icebreaking resistance can be measured.

Sommaire

A la demande du Centre de développement des transports et de la Garde côtière canadienne (GCC), le bureau d'architecture navale Kristi Maritime, Naval Architects, Inc. a mené la recherche dont il est rendu compte ici. Elle fait suite aux essais sur maquette menés à l'Institut de dynamique marine par D. Carter et associés et dont les résultats ont été publiés dans le TP 9356E intitulé "Model Tests of the Louis S. St.Laurent original bow fitted with Strakes". Le but de cette recherche était de vérifier par des essais en vraie grandeur sur un navire de la GCC les résultats des essais antérieurs sur maquette.

L'objectif fixé à la recherche en vraie grandeur a été de mesurer in situ la réduction de la résistance des glaces apportée par des stries fixées à la proue du navire.

Le navire à bord duquel ces expérimentations ont eu lieu est le brise-glace canadien Sir Wilfrid Laurier, qui était alors disponible.

Les travaux réalisés dans le cadre de cette recherche ont été les suivants: modélisation analytique fondée sur le navire choisi, calcul des stries, essais en mer et analyse des résultats.

Grâce au modèle analytique de prévision réalisé par D. Carter et associés, il a été possible de déterminer que deux stries (une par côté) fixées entre les membrures 138 et 148, c'est-à-dire dans la zone de transition reliant la proue à la partie rectiligne de la coque, à un angle d'environ 20° donneraient le résultat optimal dans le cas de glaces uniformes et compte tenu de la manière dont le navire est construit.

Pour l'étude des stries, il a été tenu compte de la réglementation canadienne sur la prévention de la pollution des eaux arctiques, des règles de classification de la Lloyd's et des valeurs de pression hydrodynamique données par le modèle analytique. L'étude détaillée proposée par les chercheurs a reçu l'agrément et de la Lloyds et de la GCC - Nord.

La fabrication et mise en place des stries a eu lieu dans les chantiers navals de MIL Davie à Lauzon (Québec) entre octobre et novembre 1989 au moment où le navire se trouvait en cale sèche, les travaux se faisant sous la direction de la GCC, région des Laurentides.

Etant donné les écarts constatés dans la hauteur réelle du pont inférieur par rapport à la cote indiquée sur les dessins, l'angle d'attaque des stries s'est trouvé légèrement modifié, mais pas au point d'influer sensiblement sur la résistance totale à la marche du navire.

Les essais en vraie grandeur ont eu lieu dans le Saguenay entre le 5 et le 9 février 1990, sous la direction de Fleet Technology Limited de Calgary.

Les résultats de ces essais ont été comparés aux résultats théoriques pour les mêmes tirants d'eau. Par ailleurs, des essais comparables ont été effectués à bord du brise-glace Anne Harvey de la GCC, et les résultats comparés aux résultats théoriques, ce qui a permis d'en tirer les corrélations nécessaires.

Les résultats des essais en mer ne permettent pas de vérifier ceux de la modélisation mathématique (réduction de la résistance à la marche de 15,3 et de 11,5 p. 100 à l'egard des deux tirants d'eau observés, respectivement) en raison surtout des incertitudes entourant la résistance à la rupture en flexion réelle des glaces dans le lieu des essais.

L'écart apparemment marqué par rapport au gain théorique déterminé à l'origine s'explique par le fait que l'immersion des stries a été moins profonde que prévu: 1) parce que le tirant d'eau observé a été moindre que le tirant d'eau de calcul établi à 6 m et, 2) à cause d'une assiette sur cul tout au long des essais.

Les observations faites de visu indiquent que l'action des stries aurait été plus efficace si ces dernières avaient été fixées un peu plus bas et un peu plus en avant sur la proue.

Il est donc proposé de mener d'autres essais en vraie grandeur durant lesquels le navire opérerait au tirant d'eau de calcul et serait équipé de deux stries supplémentaires plus petites placées au-dessous et à l'avant des stries existantes, c'est-à-dire au point de contact coque-glaces. De plus, des essais dans des conditions glacielles comparables devraient être menés à bord d'un navire-jumeau non équipé de stries, qui servirait de témoin, les données fournies par ce dernier servant de base de comparaison et permettant de calculer la réduction réelle dans la résistance de marche.

Table of Contents

		Page
1.	INTRODUCTION	1
2.	PHASE I	3
	2.1 Test Ship Inspection	3
	2.1.1 Structure	3
	2.1.2 Discussions with Operators	3
	2.1.3 Inspection Conclusions	4
	2.2 Strake Definition	4
	2.2.1 General	4
	2.2.2 Math Model Analysis	7
	2.2.3 Strake Loading	8
	2.2.4 Strake Definition - Conclusions	8
	2.3 Hydrostatic Stability	9
	2.3.1 General	9
	2.3.2 Loading Condition	9
	2.3.3 Bow Force	10
	2.3.4 Strake Ice Contact	11
	2.3.5 Open Water Performance	11
3.	PHASE II	13
	3.1 Design of Strakes	13
	3.1.1. General	13
	3.1.2. Structure	13
	3.1.2.1 CASPPR Method	13
	3.1.2.2 Lloyds Method	14
	3.1.2.3 Direct Method	15
	3.1.2.4 Structure Summary	15
	3.1.2.5 Fabrication drawings and Specification	15
	3.2 Installation of Strakes on Candidate Vessel	16
	3.2.1 General	16

Table of Contents (cont'd)

		Page
4.	PHASE III	18
	4.1 Full Scale Trials	18
	4.1.1 General	18
	4.1.2 Summary of Events	18
	4.1.3 Instrumentation	19
	4.1.3.1 Power	19
	4.1.3.2 Speed	19
	4.1.4 Ice Measurement	20
	4.1.4.1 Ice Thickness	20
	4.1.4.2 Core Samples	20
	4.1.5 Ice Trials	21
	4.1.5.1 Level Ahead	21
	4.1.5.2 Turning Trials	22
	4.2 Analysis of Results	22
	4.2.1 General	22
	4.2.2 Full Scale Results	22
	4.2.3 Math Model	23
	4.2.3.1 Background	23
	4.2.3.2 Math Model Results	24
	4.2.4 Correlation of Results	26
5.	CONCLUSIONS	32
6.	RECOMMENDATIONS	33
7.	REFERENCES	34

APPENDICES

A. Strakes - Math Model Study

B. Strakes - Structural Arrangement

C. CCGS Anne Harvey - "Carter" Model Study

List of Figures

		Page
Figure 1:	Strakes Opening Angle (Ψ)	4
Figure 2:	Strake Configuration Strake Run Frames 138 to 148	5
Figure 3:	Strake Configuration Strake Run Frames 138 to 152	6
Figure 4:	Coordinate System	7
Figure 5:	Bow Geometry	7
Figure 6:	Bow Force	10
Figure 7:	Wave Profile at 12 Knots + Static Trim on an Ice Shelf	12
Figure 8:	Speed Marker System	20
Figure 9:	Full-Scale Trial Results All Data	23
Figure 10:	Full-Scale Trial Results Selected Data	23
Figure 11:	Resistance vs Ship Speed Condition 1: Level Trim Ice Flexural Strength: 670 kPa	26
Figure 12:	Resistance vs Ship Speed Condition 2: Trimmed Waterline Ice Flexural Strength: 670 kPa	27
Figure 13:	CCGS Anne Harvey Resistance vs Ship Speed Ice Flexural Strength: 200 kPa	29
Figure 14:	Resistance vs Ship Speed Condition 1: Level Trim Ice Flexural Strength: 500 kPa	30
Figure 15:	Resistance vs Ship Speed Condition 2: Trimmed Waterline Ice Flexural Strength: 500 kPa	30

List of Tables

		Page
Table 1:	Loading Conditions	9
Table 2:	Beached Condition	10
Table 3:	Trial Drafts	24
Table 4:	Loading Condition 1 - Dynamic Forebody Waterplane Geometry	24
Table 5:	Loading Condition 2 - Dynamic Forebody Waterplane Geometry	25
Table 6:	Math Model Results	25
Table 7:	CCGS Anne Harvey - PAPA Trials	28
Table 8:	Math Model Results CCGS Anne Harvey	28

1. Introduction

For low icebreaking resistance in bow forms designed for breaking in bending it is essential to keep the flare angle as flat as possible out to the full beam of the vessel.

On a number of commercial contemporary icebreakers this has been accomplished with the introduction of chine hull forms.

On traditional hulls, however, a rounded shoulder area occurs at the transition to the midbody, giving rise to high crushing loads and hence increased resistance in ice covered waters.

In an attempt to evolve an effective low-cost method of reducing these crushing forces, Dr.D.Carter had suggested that by fitting shallow angle "fins" (strakes) as appendages at the shoulder area of the hull the ice cover would be deflected downward as the ship advances thus breaking in bending rather than crushing.

This theory was tested using a math model developed by Dr.D.Carter and subsequently model tested (1).

The results of this work indicated that substantial reductions in icebreaking resistance could be realized with the fitting of the strakes and as a result a ship trial was jointly commissioned by the Transport Development Centre (TDC) and the Canadian Coast Guard (CCG), Transport Canada, to verify in full scale the analytical and model test results.

Selected because of availability, a Type 1100 Icebreaking Buoy Handling vessel, the CCGS "Sir Wilfrid Laurier" was fitted out with strakes and subsequently tested in the Saguenay River in March 1990.

This study has been conducted in three distinct phases as follows:

Phase I

- Inspection of the test ship in order to analyze its bow structure, to control any previous damage due to ice and to ascertain its operating conditions, so as to be able to establish location of the strakes and evaluate probable loads.

- Definition of the strakes dimensions, number, angle of attack and location; calculation of applied loads and of the predicted improvement obtained for a number of strake installations, based upon results from the Carter Strakes model.

- Evaluation of the hydrostatic stability of the ship during icebreaking operations in order to define the ice contact area on the bow.

Phase II

- Design of the strakes structure and preparation of drawings and specifications suitable for fabrication. (Design to approval of recognized classification society (Lloyds) and Canadian Coast Guard Northern Arctic Ship Safety (AMNB).

- Installation of strakes on candidate vessel.

Phase III

- Full-scale trial of candidate vessel.

- Analysis of results.

This report details the work carried out in each of the these phases.

2. Phase I

2.1 Test Ship Inspection

2.1.1 Structure

CCGS "Sir Wilfred Laurier" is a Type 1100 Icebreaking Buoy Handling vessel conforming to the Canadian Arctic Shipping Pollution Prevention Regulations for a vessel of Class 2.

Frame spacing is 400 mm throughout with 31.5 mm shell plating on the bow and 24 mm in the midbody in the ice belt area. Shell plate in the ice belt is grade EH36.

The vessel was surveyed while afloat at Trois-Rivieres, Quebec on 7 April 1989 and internal structure over the area anticipated to be effected by installation of the strakes was verified against the "as fitted" structural drawings as prepared by the builder.

The shoulder area is adjacent to the forward part of the Cargo Hold and was readily accessible for survey since no linings or insulation are fitted in this space.

Damage reports for this vessel indicated that, as of the date of the survey, damage to the hull had been limited to the bottom shell only.

Damage survey reports for sister ships CCGS "Martha L. Black" and CCGS "George R. Perkes" obtained from CCG also indicated that structural damage to these vessels, after having operated in "severe" Arctic conditions, had been limited to the bottom shell area, generally below the 2.4 m waterline.

2.1.2 Discussions with Operators

Discussions were held with the vessel's operators in order to determine the vessel's "normal" sailing trim and possible effect on the overall operations, particularly as applied to buoy handling, with the installation of the strakes.

Aerial photographs available from the operators showed a wave profile of the vessel in open water at a cruising speed of about 12 knots which were subsequently used to assess the possible effect on the open water performance of the vessel. At this time it was stated that the vessel was normally operated at or near an even keel draft of 6.0 m.

The buoy handling boom for this vessel is arranged such that the boom heel is located at the house front resulting in the boom hook being immediately adjacent to the hull shoulders.

Encroachment into this area raised concern with regard to buoy launching and recovery and subsequently a full-scale mock-up of a strake on the vessel was used for a test, which proved that the fitting of the strakes would not affect this aspect of the vessel's operation.

2.1.3 Inspection Conclusions

As a result of the vessel inspection it was concluded that the fitting of the strakes on the vessel would be relatively straightforward and that no allowance need be made for trim in the angle of attack.

Area of application of the strakes was free from structural damage from ice operations.

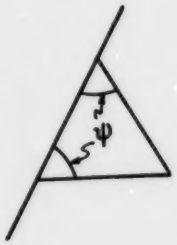
2.2 Strake Definition

2.2.1 General

As a result of the ship inspection, structural arrangements and examination of the hull lines, it was concluded that strake configurations in the area of frame 138-152 at the waterline should be analyzed.

A total of five different strake configurations were investigated, as shown diagrammatically in Figures 2 and 3, two of which, the 15 and 20 degree angle strakes, were further analyzed for the effect of varying the opening angle as shown in Fig.1 from 30 to 90 degrees.

Figure 1
Strakes Opening Angle (Ψ)



In addition, the effect of one pair of strakes each side was considered.

In determining the end points for strake application consideration was given to landing on existing strong members such as deep webs, flat and stringers in order to provide adequate structural support without extensive internal additional steelwork.

Since the support structure was located in the open hold any additional internal stiffening to prevent local buckling could be readily installed if required.

Figure 2
Strake Configuration
Strake Run Frames 138 to 148

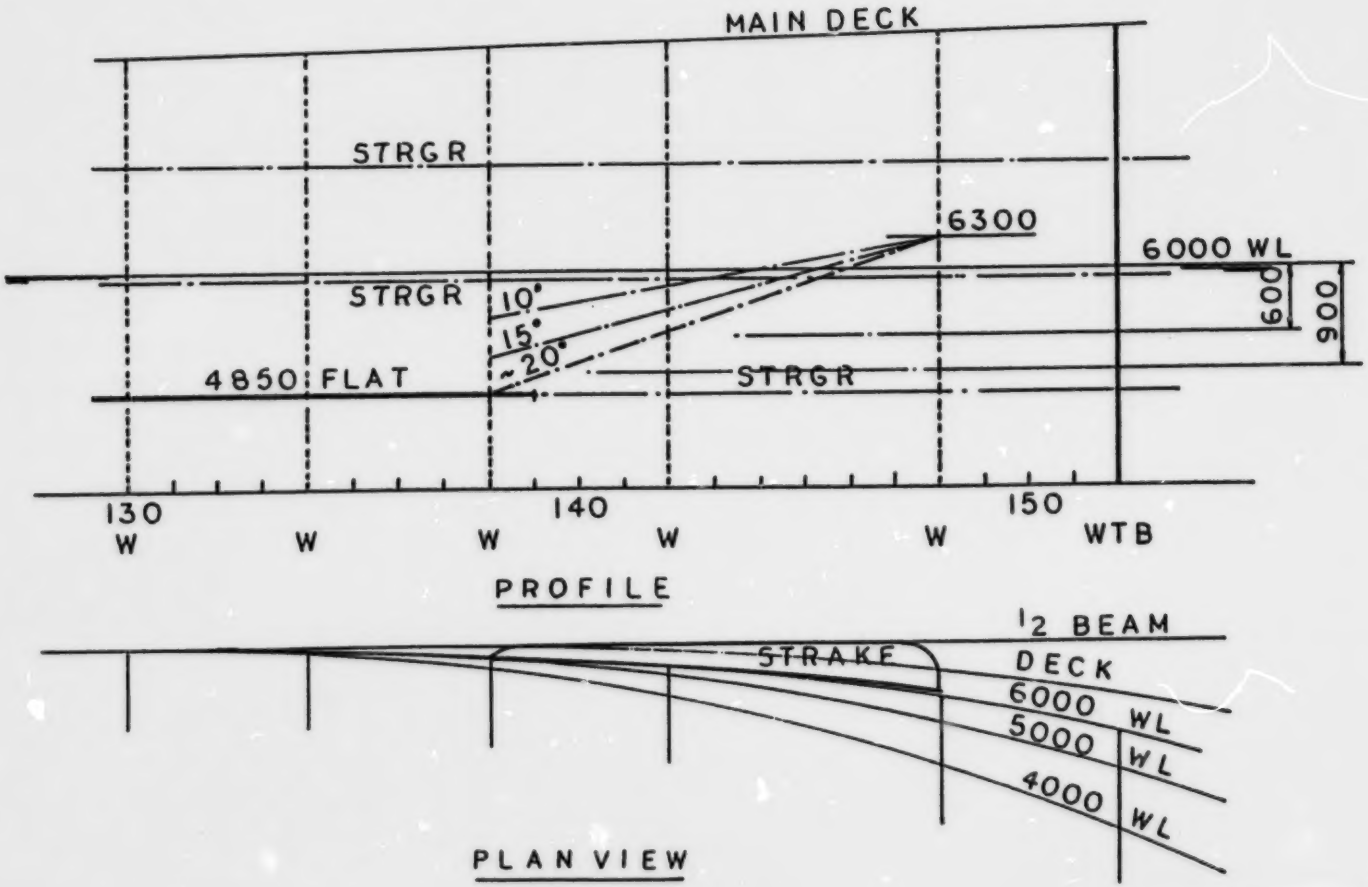
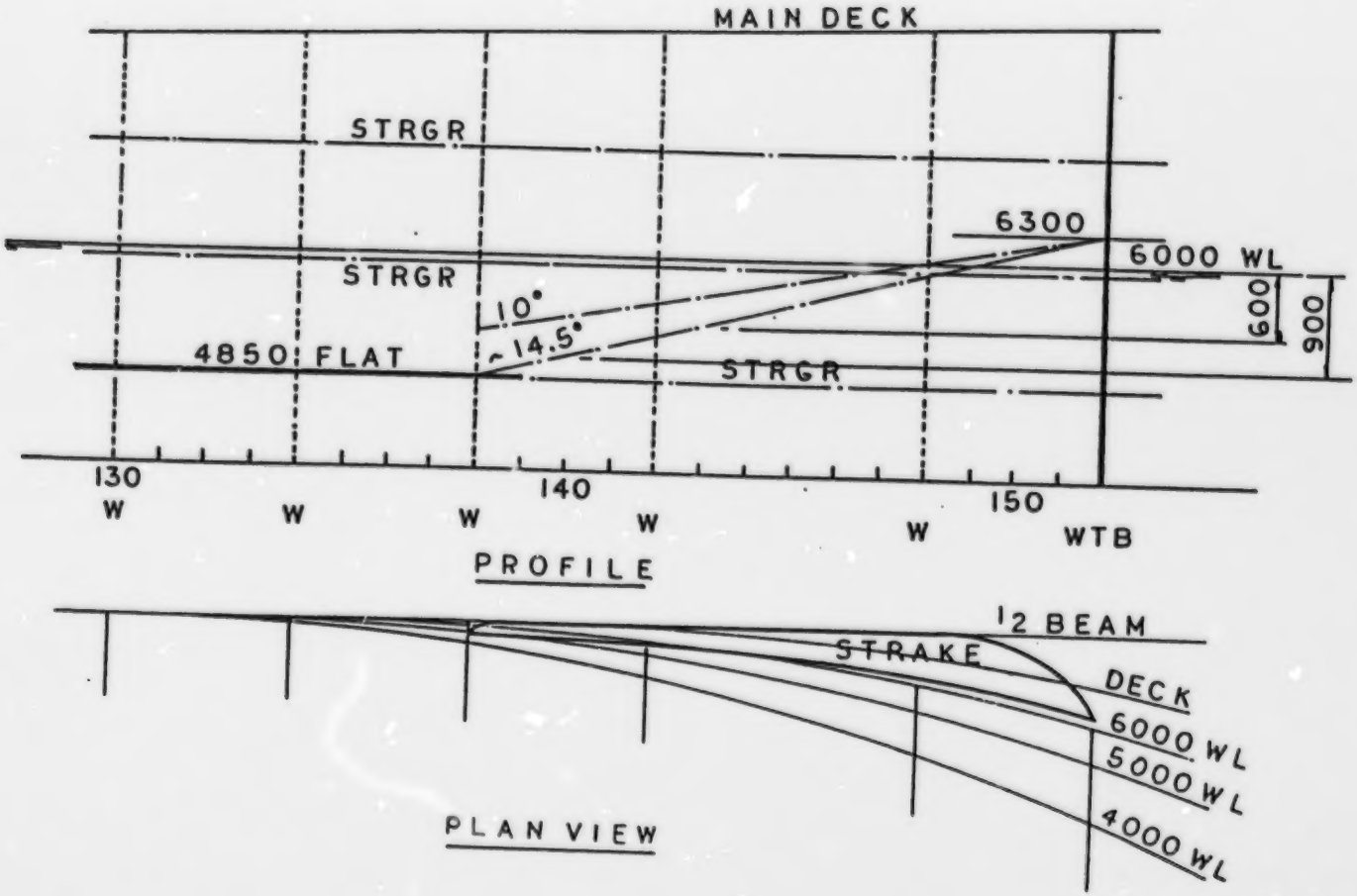


Figure 3
Strake Configuration
Strake Run Frames 138 to 152



2.2.2 Math Model Analysis

Hull characteristics for the CCGS "Sir Wilfrid Laurier" were lifted from Collingwood Shipyard Lines Plan, Drawing No. LEC-230-401 in accordance with the coordinate system as shown in Fig. 4 and are presented graphically in Figure 5.

Figure 4
Coordinate System

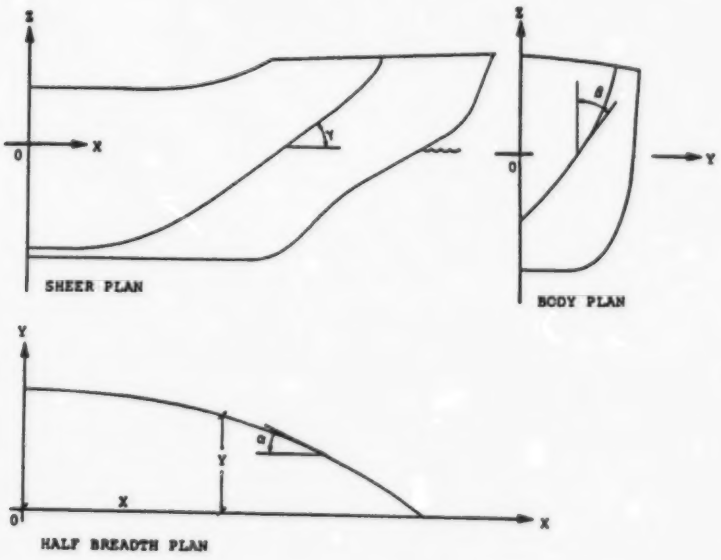
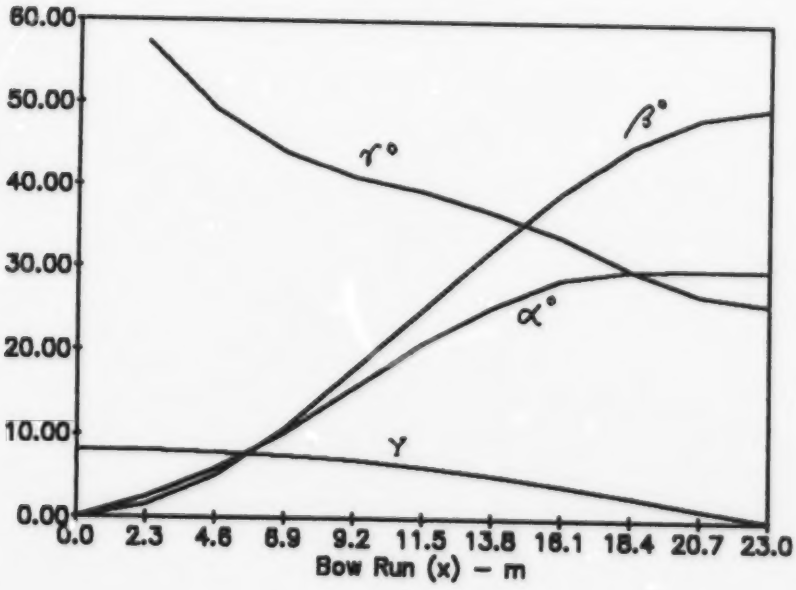


Figure 5
Bow Geometry



The change in angles at the shoulders due to the introduction of the strakes are not included in these plots, since they were to be introduced in the math modelling.

Analysis was carried out by "Donald Carter and Associate Consultants". A copy of the report is included with this report as Appendix A.

It may be seen from this report (Table 2) that over the range of strake configurations investigated the reduction in resistance varied from 30 to 35 per cent. Further, although the strake with 14.52° slope gave the best reduction in resistance at 35%, this is only a 1% improvement over the 19.93° strake which is far better integrated into the existing support structure.

The influence of the strake spread angle was optimal in the range of 60-75 degrees with 60 degrees being selected to facilitate ease of fabrication.

The introduction of two pairs of strakes each side resulted in a slight increase in the submergence component of the resistance and, therefore, a single strake each side was recommended.

2.2.3 Strake Loading

Strake loading was determined assuming the vessel was proceeding at a speed of 2 knots in one 1 m of level first year ice with a flexural strength of 500 kPa and a crushing strength of 1565 kPa.

The vertical peak load on each strake was calculated to be 25 t i.e. 50 t total load.

2.2.4 Strake Definition - Conclusions

The main conclusions drawn from this analysis are as follows:

- Strakes should be run from frames 138-148 with leading edge landing on the web frame at 148 at 6300 mm above the baseline and trailing edge landing on the flat at 4850 mm above baseline.
- Resultant angle of attack - 19.93°.
- Spread angle - 60°.
- One strake each side.
- Peak load one side 25 t.

2.3 Hydrostatic Stability

2.3.1 General

Hydrostatic stability was evaluated based upon operator supplied information which states that the vessel is normally run at or close to 6.0 m even keel draft.

In addition to determining the bow force and static stability on an ice ridge (beached condition) a wave profile at approximately 12 knots was developed from the aerial photographs supplied by ship personnel on which the effect on open water performance could be assessed.

2.3.2 Loading Condition

Icebreaking loading conditions were extracted from the Trim and Stability Book for the vessel as prepared by the builder (Collingwood Shipyards) and are summarized in Table 1.

It was determined from the hydrostatics particulars that at 6.0 m even keel draft the displacement for the vessel is 4940 t which falls between conditions A1 and A5, however, for heavier ice conditions the flume tank is dumped thus the free surface moment (FSM) correction has been adjusted accordingly for the test condition.

Based on the foregoing and for the purpose of stability calculations a vertical centre of gravity of 6.4 m and a free surface moment correction of 1780 tm were assumed.

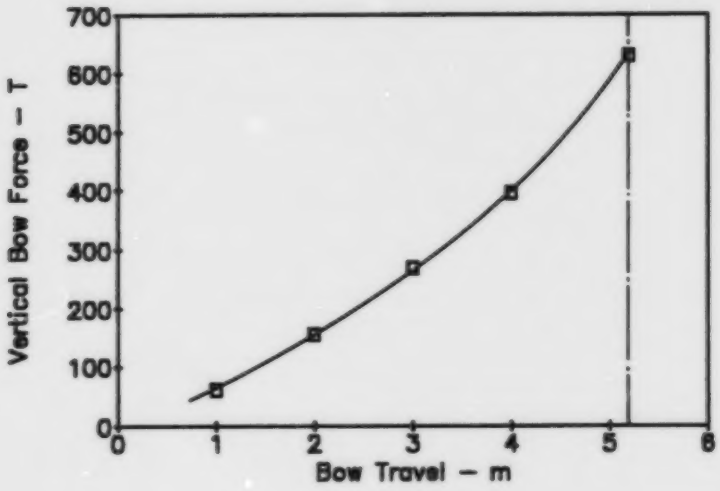
TABLE 1
Loading Conditions

Loading Conditions	Tonnes	KG (m)	FSM (tm)	Remarks
A1 Ballast Departure	4879	6.27	2966	Flume Operating
A2 Ballast Mid-Voyage	4462	6.52	1780	Summer Arctic IB
A3 Ballasted	4411	6.76	749	Leaving Arctic
A4 Ballast Arrival	3998	6.80	610	
A5 Loaded Departure	5025	6.40	2625	Flume Operating
A6 Loaded Mid-Voyage	4665	6.51	1581	
A7 Loaded Leaving Arctic	4424	6.69	587	
A8 Loaded Arrival	4396	6.69	480	
A9 Arctic Buoy Handling	4492	6.61	1535	Buoy on Boom

2.3.3. Bow Force

Figure 6 indicates the resultant bow force plotted against bow travel for the vessel in static equilibrium on an ice shelf. Bow travel is the horizontal distance travelled forward into the ice sheet from the point of bow contact to any given point on the stem up to a limit of the iceskeg contact. Initial condition is for the vessel on an even keel draft of 6.0 m. No allowance is made for ice crushing, therefore, point of contact is assumed at the stem bar.

Figure 6
Bow Force



Using the initial loading condition as per Section 2.3.2 the resultant stability in the beached condition with the vessel hard up to the iceskeg is as shown in Table 2. Static draft at the aft perpendicular is 7.518 m giving 0.105 m freeboard. Actual freeboard would be somewhat greater since calculations are based on moulded hull excluding appendages (shell, rudder, propellers and bossings).

TABLE 2

Beached Condition	Tonnes	KG (m)	Moment (tm)
Free Floating	4886.2	6.400	31272
Bow Force	629.0	3.214	2022
Beached	4257.2	6.871	29250
Stability:			
	KMt =	7.560	m
	KG =	6.871	m
	GMs =	0.689	m
	FS =	0.364	m
	GMf =	0.324	m

2.3.4 Strake Ice Contact

With the vessel at even keel on 6.0 m draft and assuming 1 m thick level ice the contact area on one strake is approximately 6400 cm^2. As the vessel rides up on the ice the contact area rapidly diminishes since the trapezoidal shape of the strake has the greater area forward. At 0.5 m bow rise the contact area reduces to 4500 cm^2. with the trailing edge now rising to above the bottom face of the ice sheet. At 1.0 m bow rise the contact area is further reduced to about 2400 cm^2. with the strake now making contact with just 50% of the thickness of the ice cover. Assuming the vessel hard up to the iceskeg, with the point of contact of the bow at the upper face of the ice sheet, the strake is clear over the top of the ice approximately 0.75 m. (Fig. 6).

The trapezoidal shape of the strake was directed by the requirement to have the outboard edge at or within the full beam of the vessel.

As such, at lighter drafts or with trim of the vessel by the stern, the effectiveness of the strake is substantially reduced.

2.3.5 Open Water Performance

Figure 7 shows the wave profile over the length of the vessel at a speed of about 12 knots (open water cruising speed).

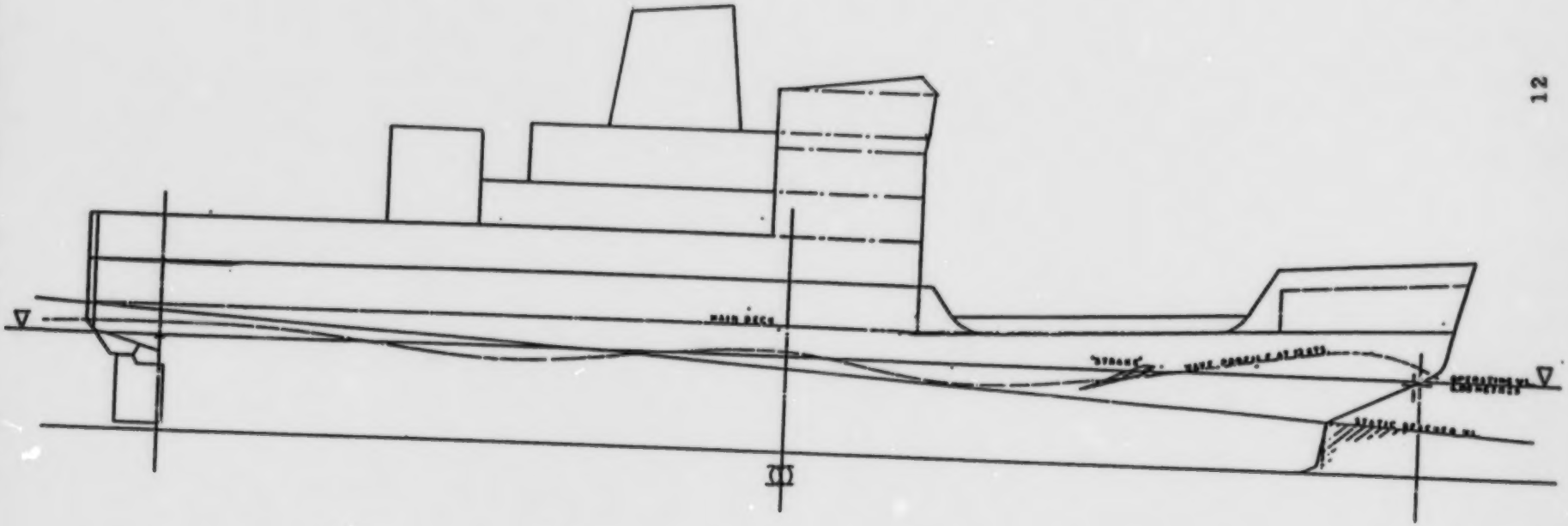
Examination of this figure shows the strakes immersed about one third of their length to a depth of approximately 0.5 m with the angle of incidence between the wave waterline and the strake in the order of 12^{o} .

The depth of the strakes (measured outboard of the beam of the vessel) at the waterline is 0.18 m whereas the thickness of the boundary layer at the strake/waterline interface in turbulent flow has been calculated to be 0.12 m (7). Assuming the strakes in a clean flow the total load (resistance) on the strakes would be in the order of 160kg or about 1% of the total resistance of the vessel.

Based upon the foregoing and on observations made during open water transit it was concluded that the effect of the strakes on open water resistance at cruising speed will be negligible.

Figure 7

Wave Profile at 12 Knots
+
Static Trim on an Ice Shelf



3. Phase II
3.1 Design of Strakes
3.1.1 General

The configuration of the strakes was determined in Phase I of the project. The requirements for fabrication and installation called for Classification (Lloyds) and Canadian Coast Guard Northern Arctic Ship Safety (AMNB) approval.

Since the strakes are experimental in nature and novel by design no specific rules apply to structural requirements.

The approach taken was to consider the strakes as appendages similar to double plate bilge keels and apply existing Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR) and Lloyds Ice Class ACI assuming the strakes as an extension of the shell plating.

In addition removal of the strakes was required to be considered as well as maintaining structural integrity of the main hull in the event of extreme loads on the strakes.

3.1.2 Structure
3.1.2.1 CASPPR Method

From Schedule VI "Hull Design for Arctic Class Ships" Section 7 thickness of the shell plating (t) in each area specified shall not be less than the spacing of main frames multiplied by the factor obtained from the formula:

$$\text{factor} = \frac{2}{3}\sqrt{\frac{P}{f}}$$

where P = ice pressure Mpa (Table II)
f = Yield stress of steel MPa

Since the CCGS "Sir Wilfred Laurier" was designed to meet Class 2 of these regulations similar class is used for strake design.

Therefore: For strake plating in bow area using shortest span in largest strake panel (250 mm):

$$t = 250 \times \frac{2}{3}\sqrt{\frac{4.14}{235}} = 22.12 \text{ mm}$$

and in midbody area

$$t = 250 \times \frac{2}{3}\sqrt{\frac{2.76}{235}} = 18.06 \text{ mm}$$

3.1.2.2. Lloyds Method

From Lloyds " Rules and Regulations for the Classification of Ships" Part 3, Ship Structures, Chapter 10, Section 5.5, Bilge keel and ground bars, states in part:

- In general, bilge keels are to be attached to a continuous ground bar. (5.5.2)
- The minimum thickness of the ground bar is to be equal to the thickness of the bilge strake or 14mm whichever is the lesser (5.5.3)
- Material to be generally similar to that of the hull envelope in way of attachment. (Part 3, Chapter 2, Table 2.2.1, Note 6)
- Bilge keels to be gradually tapered at ends. (5.5.7)

From Part 3, Chapter 9, Section 9, " Strengthening requirements for ships intending to operate in multi-year ice conditions", Subsection 9.8 requires that in way of the ice belt the thickness of the shell plating is not to be less than:

$$t = 0.5\, s \alpha_p \beta \gamma \sqrt{\frac{P}{\sigma_o}} + c \text{ mm}$$

where
- s = frame spacing mm
- α_p = longitudinal distribution factor
- β = vertical distribution factor
- γ = power displacement factor
- p = design ice pressure
- σ_o = yield stress of steel
- c = corrosion abrasion increment

For this application requirements for a vessel of Ice Class ACI is used which by definition are "intended for ships designed to navigate in Arctic or Antarctic ice conditions equivalent to unbroken ice with a thickness of 1.0 metre".

For CCGS "Sir Wilfred Laurier" the power factor is

for the bow : 0.927
and for the midbody : 0.741

Plating thicknesses have been determined for the largest strake panel which gives an unsupported span of 250 mm with the following results.

for the bow : t = 18.34 mm

and for the midbody : t = 11.73 mm

3.1.2.3. Direct Method

The calculated vertical peak load from the Carter model for the strakes in 1.0 m of ice with 500 kPa bending strength is 25 t for one side only. Using a 100% safety margin the average pressure on the face of the strake is 2.75 MPa.

Reference 2, page 183 gives maximum unit stress on the surface of the plate for a panel with all edges supported as:

$$S = \frac{CwL^2}{t^2}$$

C = non-dimensional stress support factor

w = unit applied load

L = length on shortest span

t = plate thickness

Using largest panel (400 mm x 250 mm) and a plate thickness of 19 mm the maximum unit stress is 225 MPa (0.96 x yield) based upon peak load + safety margin and 113 MPa (0.48 x yield) for "working" peak load.

3.1.2.4 Structure Summary

Based upon the calculations carried out and considering the strakes to be located in the existing midbody area of the vessel (shell plating 24 mm thickness) it was concluded that a plating thickness of 19 mm would meet the strength requirements and that the ground bar (shell doubler) should be 15 mm in thickness.

Other structural details of the strakes were developed to suit practical fabrication and application to the hull.

The strake/doubler weld connection was designed to fail prior to doubler/hull connection to protect the main hull plating from damage in the event of extreme loads on the strakes.

3.1.2.5 Fabrication drawings and Specification

A detailed structural design drawing was prepared along with a specification suitable for a contractor to fabricate and install the strakes on the test ship.

Structural details were submitted and approved by both Lloyds Classification and Canadian Coast Guard.

In the case of Canadian Coast Guard (AMNB) approval a requirement was put forward for additional internal structure at frames 144, 145, 146 and 147 in the form of web brackets to be installed in the event of the vessel proceeding to the Arctic environment.

The structural design drawing as submitted and approved is included as Appendix B with this report.

3.2 Installation of Strakes on Candidate vessel

3.2.1 General

Fabrication and installation of the strakes was carried out at M.I.L. Davie Inc., Lauzon, Quebec during a refit period October/November 1989 under the direction of CCG Laurentian Region.

A total of three visits were made to the shipyard by the designer during the installation period in order to monitor the installation of the strakes to ensure compliance with the design philosophy.

Lloyds grade E steel was substituted for grade EH36 as specified for the doubler to the shell due to lack of availability of EH36 at the time of installation. It was considered that this modification would have no significant effect on the overall structural strength of the strake installation.

In addition, the contractor requested to change the weld connection at the strake/doubler interface to a full penetration weld at both top and bottom faces in lieu of the slot weld closing plate method, as designed, which was also accepted.

The design of the strakes called for the leading edge "nose" to land on web frame 148 at a point 6300 mm above the baseline with the trailing edge to land at the intersection of the 4850 mm flat and web frame 138.

With the vessel in drydock the actual height of the flat was checked above the keel and found to be 4906 mm on the starboard side and 4850 mm on the port side. Height of the leading edges was therefore adjusted to 6485 mm above the baseline for both port and starboard strakes. The resulting angle of attack then became 21.5 degrees on the starboard side and 20.8 degrees on the port side. The change in resistance as a result of this modified angle is considered small.

Due to cost restraints the web brackets were not installed at this refit, it being planned to have this additional stiffening added with the vessel alongside if and when the vessel is called upon for an Arctic voyage and assuming the strakes are retained.

A ship trial was carried out in open water on 15 November 1990 to test other newly installed equipment.

Although the vessel was at a relatively light draft on these trials (5.20 m forward and 5.75 m aft) it was evident, based upon observed clearance of the strakes in the first wave trough, that there would be little if any effect on the open water performance at deeper drafts.

It was also observed that in a 180 degree turn in relatively choppy conditions, that the strakes acted as a "spray guard" keeping water off the working deck.

4. PHASE III
4.1 Full Scale Trials
4.1.1 General

Full scale ice trials were carried out on the Type 1100 Icebreaker CCGS "Sir Wilfred Laurier" in the Saguenay River from February 5th to 9th 1990.

The purpose of these trials was to measure the effect of Strakes as applied to a Canadian Coast Guard Icebreaker with the intent of comparing these results with theoretical predictions as determined from a math model developed by Dr.D.Carter.

It was understood at the outset of these trials that the vessel was on stand-by operations and in fact the vessel was called away from testing to carry out escort operations. These activities did not seriously effect the overall trials program.

Trials were carried out by Fleet Technology Limited of Calgary, under the project management of Mr. Bruce Cowper. Other personnel on board for the trials included:

Mr. D. Gauvin	Canadian Coast Guard, Ottawa, Ont.
Mr. J. Laframboise	Transport Development Centre, Montreal, Qc.
Mr. R. Ritch	Fleet Technology Ltd., Calgary, Alta.
Mr. J.E. Carter	Kristi Maritime Inc., Pointe Claire, Qc.

The following observations were made during these trials with reference to methods employed for various aspects of data gathering and trial procedures.

For a full report and results of these ice trials see Transport Development Centre, Report TP# 10554E (3).

4.1.2 Summary of Events

Date	Activity
5-6 Feb.	Installation of telemetry equipment, video equipment etc.
7 Feb.	Ice measurement. Testing ahead in level ice.
8 Feb.	Ice measurement. Testing ahead with vessel trimmed by stern to lift strake. Turning in level ice.
9 Feb.	Decommission equipment.

4.1.3 Instrumentation
4.1.3.1 Power

Both port and starboard tail shafts were instrumented to measure torque, RPM and thrust. Strain gauges were located on each shaft to measure the torque and thrust while RPM was picked up on the turning gear mechanism.

Strain signals were transmitted via FM telemetry to receivers in the shaft compartment and then to the data acquisition system located in the wheelhouse.

4.1.3.2 Speed

The principal method for determining ships speed throughout the trials was with the use of a video camera mounted outside on the safety rail at the starboard forward corner the wheelhouse.

Video recordings were synchronized with the data acquisition system with the time display imprinted on the video recordings.

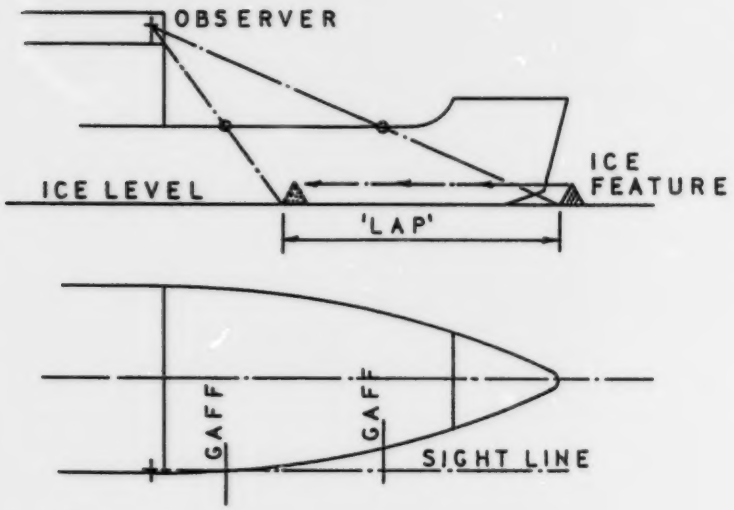
A calibrated grid 8m x 8m subdivided into 2m x 2m sections was layed out on the ice and recorded prior to testing. Using slow motion playback, it was possible then to time an ice feature over the prerecorded grid and thus determine average speed of advance in the icebreaking mode.

In addition, and in order to determine "steady state" during any given test run, two tape markers were arranged on the starboard bulwark and then, using a line of sight measurement onto the ice from the wheelhouse position, stopwatch measurements were taken for an ice feature to travel between these two markers and subsequently average speed calculated from the fixed length/lap time measurements.

The tape markers proved to be somewhat difficult to accurately align with any ice feature and, therefore, the marker system was modified such that at each marker location a gaff was extended out from the side of the vessel over the ice as shown in Fig. 8 which gave a much increased range of ice features to be used in timing and reduced danger of parallax inaccuracy.

In addition to the "speed" video recordings, a hand held video camera was utilized for general trials observations. The buoy boom was swung out to starboard for a number of the runs, the angle of heel being offset by buoy sinkers on the port side. From a cage swung off the boom an excellent vantage point was created from which the action of the bow and strakes in the ice could be observed and recorded.

Figure 8
Speed Marker System



4.1.4 Ice Measurement

4.1.4.1 Ice Thickness

Ice thickness was measured through bore holes using a tape onto which a steel rod with a trip string was attached to "lock" the rod under the ice.

Both ice thickness and snow cover were recorded. It was noted that in a number of areas, the ice cover consisted of columnar ice with both a "snow-ice" and snow cover.

Ice thickness measurements were recorded along the track at 1 x ship length intervals.

Ice thickness in general was uniform with snow cover varying with drifts formed by the prevailing wind.

4.1.4.2 Core samples

A total of six core samples were taken over the test period for the purpose of estimating the flexural ice strength using temperature and salinity data. Cores were extracted using a power driven ice coring tool and core temperatures measured immediately upon extraction using a hand drill and probe thermometer.

Ice cores were then stored for return to the vessel for salinity measurements to be taken from the melted samples.

Salinity of the samples was determined using a Bechman Solubridge Model RB-5 salinity meter and checked using a refractometer type salinometer.

4.1.5 Ice Trials
4.1.5.1 Level Ahead

On February 7, 1990, the vessel was tested in two tracks off Cap Rouge.

Prior to testing, ballast and oil fuel was arranged to bring the vessel as close as possible to the strakes design draft of 6.0 m.

In order to achieve this draft a number of buoy sinkers had been loaded at Quebec City which proved to be an additional asset later in the trials for offsetting the buoy boom during video tapings.

Because of limitations in operational areas dictated by the normal Saguenay River traffic lane and "ice fishing villages", areas were selected such that the test runs were perpendicular to the main traffic lane with a limit of 2000ft from the shore line being imposed by the authorities.

From the ice thickness measurements, it was concluded that the vessel would be working in conditions near to maximum capability and, therefore, in order to determine the "minimum" power required to transit, the vessel was brought to the ice edge and stopped. Power was gradually increased using the wheelhouse RPM indicator as a measure until the vessel began to move ahead. The RPM was noted and the vessel then backed along the channel to a position 1-2 ship lengths from the start of the test run area. Power requirement as determined from the "start-up" test was then called for and the vessel accelerated into the ice field.

When speed in the ice had stabilized, the vessel was run for 1-2 ship lengths in this "steady-state" with the data acquisition system recording.

The vessel was tested at various power levels over the track lengths up to the limit line as observed from the radar.

On February 8, 1990 the vessel was again tested in level ice this time off Pointe Trinity.

The first set of tests on this day were run with the vessel at static drafts of 6.0 m forward and 5.85 m aft. In an attempt to measure the effect on icebreaking capability "without" the strakes, fuel oil was transferred aft, the forward deep ballast tank emptied and the buoy sinkers moved as far aft as practical on deck to raise the bow. For this series of tests the static drafts forward and aft were 5.53 m and 6.13 m respectively.

Although this movement of liquids and sinkers did bring the bow up, it was observed during the subsequent trials that the strakes still made contact with the ice sheet during the trial runs.

Procedure for tests carried of Pointe Trinity was as for those carried out off Cap Rouge.

4.1.5.2 Turning Trials

On February 8, 1990, channel break out and turning circle tests were carried out in the vicinity of Pointe Trinity.

Turning circles were attempted at both 20 deg. and full rudder. It was noted that while the vessel broke out of the channel very effectively that once the vessel speed reduced to about 2 knots no further turning could be detected, the twin-screw/single rudder arrangement providing ineffective turning moment at this speed in the prevailing ice thickness.

4.2 Analysis of Results

4.2.1 General

The original prediction for performance of the test ship fitted with strakes was based upon results from the math model in which predetermined draft and trim and ice strength had been assumed.

The "Carter" model calculates performance using a fixed waterline with no allowance for induced trim during icebreaking as was experienced in the full-scale trials.

In the following analysis the actual icebreaking drafts as observed and ice strength as encountered in the field trials have been used.

4.2.2 Full Scale Results

Results of the full scale trial measurements have been extracted from (3) and are indicated graphically in Figure 9. Nett shaft thrust includes thrust deduction due to propeller/ice interaction and, therefore, is equal to ship resistance. The scatter in the data points in this figure is significant and is attributed to varying snow cover and temperature over the test period.

Fig. 10 indicates a selected set of data points in which the snow cover, temperature and ice thickness are essentially the same for both static level keel and "trimmed" conditions.

Figure 9
All Data

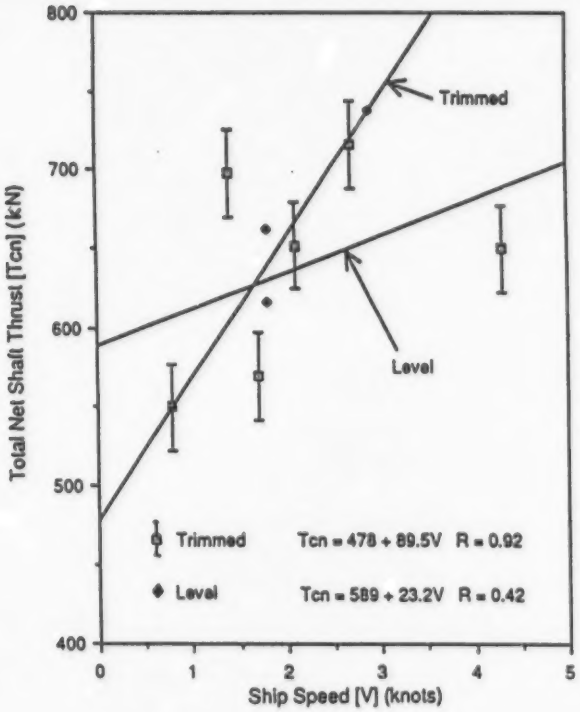
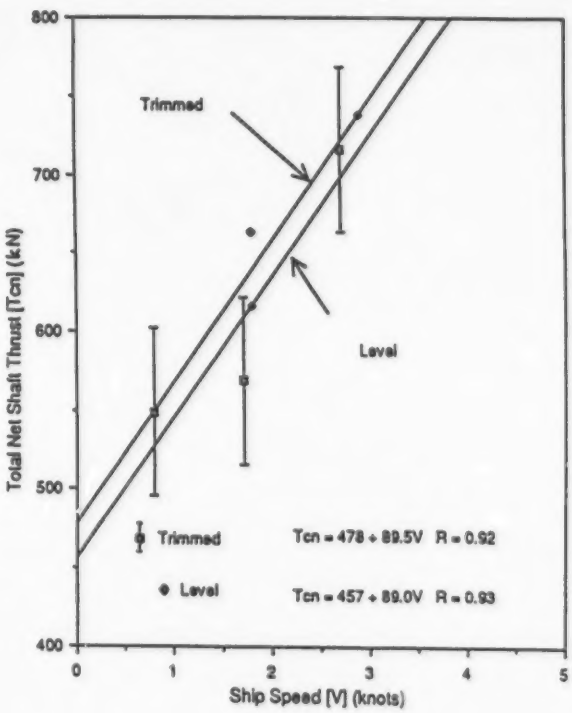


Figure 10
Selected Data



4.2.3 Math Model

4.2.3.1 Background

The original results of the "Carter" model (1) indicated that a reduction in resistance in the order of 30% could be obtained with the fitting of the strakes on the test ship.

This prediction was based upon an even keel draft of 6 m, ice flexural strength of 500 kPa and a friction coefficient of 0.1 for the vessel in 1 m thick level ice.

The design draft of 6 m even keel could not be achieved on trials due to the lack of deadweight.

It was observed during the level icebreaking trials that the vessel adopted a virtual permanent trim by the stern due to the vertical force acting on the bow at the stem/ice interface which resulted in lifting the strakes to a position above the ice which substantially reduced their effectiveness. The strakes did not contribute to this dynamic trim since their contact with the intact ice sheet was minimal. The drafts as observed are summarized in Table 3.

Table 3

Trial Drafts			
Loading Condition	Draft Aft	Draft Fwd	Notes
	m	m	
Condition 1	6.10	5.75	Observed in ice
Condition 2	6.42	5.20	Observed in ice

4.2.3.2 Math Model Results

Just prior to the ice trials the vessel had completed a refit in which, in addition to the fitting of the strakes, the Inerta 160 low friction hull coating had been refurbished.

It is recognized that friction is a major factor in resistance and in the absence of full scale measurements a friction coefficient of 0.06 has been assumed for the math model which is typical for new Inerta 160.

Tables 4 and 5 show the forebody waterplane geometry for the test ship for the trim conditions as indicated in Table 3.

Table 4

Loading Condition 1				
Forebody Waterplane Geometry				
Draft Fwd : 5.75 m Draft Aft : 6.10 m				
Bow Run to Strake : 5.8 m				
Strake Angle to Waterline : 21.4 deg.				
Bow Run	0.5 Beam	Alpha	Beta	Gamma
m	m	deg.	deg.	deg.
0.00	8.10	0.0	0.0	0.0
3.75	7.95	4.6	3.5	50.0
7.50	7.41	12.0	12.5	44.5
11.25	6.25	21.6	27.0	39.5
15.00	4.45	30.0	42.7	31.0
16.88	3.40	30.4	48.0	28.0
18.75	2.27	30.4	50.2	26.3
20.63	1.22	30.4	50.2	26.3
22.50	0.00	30.4	50.2	26.3

Table 5

Loading Condition 2				
Forebody Waterplane Geometry				
Draft Fwd : 5.28 m Draft Aft : 6.42 m				
Bow Run to Strake : 5.8 m				
Strake Angle to Waterline : 22.4 deg.				
Bow Run m	0.5 Beam m	Alpha deg.	Beta deg.	Gamma deg.
0.00	8.10	0.0	0.0	0.0
3.75	7.93	5.3	3.7	50.0
7.50	7.33	13.5	14.6	44.0
11.25	6.05	24.5	33.0	36.0
15.00	3.95	31.2	50.3	26.9
16.88	2.83	31.2	50.3	26.9
18.75	1.60	31.2	50.3	26.9
20.63	0.56	31.2	50.3	26.9
21.43	0.00	31.2	50.3	26.9

Based on the foregoing data the math model was run for the test ship in both loading conditions at the observed trim lines using a full scale ice flexural strength of 670kPa and for a normalized ice thickness of 0.883 m all as per the full-scale trial report (3). Results are summarized and presented in Table 6.

Table 6

MATH MODEL RESULTS		
Level Ice Resistance (kN)		
Ice Flexural strength : 670 kPa		
Ice thickness : 0.883 m		
Condition 1		
Speed m/s	No strakes	With Strakes
0	932	818
1	988	837
2	1138	999
3	1355	1150
Condition 2		
Speed m/s	No strakes	With Strakes
0	920	815
1	975	863
2	1124	994
3	1338	1185

4.2.4 Correlation of Results

Examination of Table 6 "Math Model Results" shows no appreciable change in the icebreaking resistance for the vessel with or without strakes as a result of increased trim by the stern.

The application of the strakes is predicted to reduce the icebreaking resistance by 15.3% at 1 m/s in Condition 1 and 11.5% at 1 m/s in Condition 2.

In the following analysis the full scale selected data regression line is used for correlation with the math model results.

Figure 11 indicates the full scale resistance and math model predictions plotted against ship speed for Condition 1 and Figure 12 compares the results for Condition 2.

Figure 11
Resistance vs Ship Speed
Condition 1
Ice flexural strength: 670 kPa

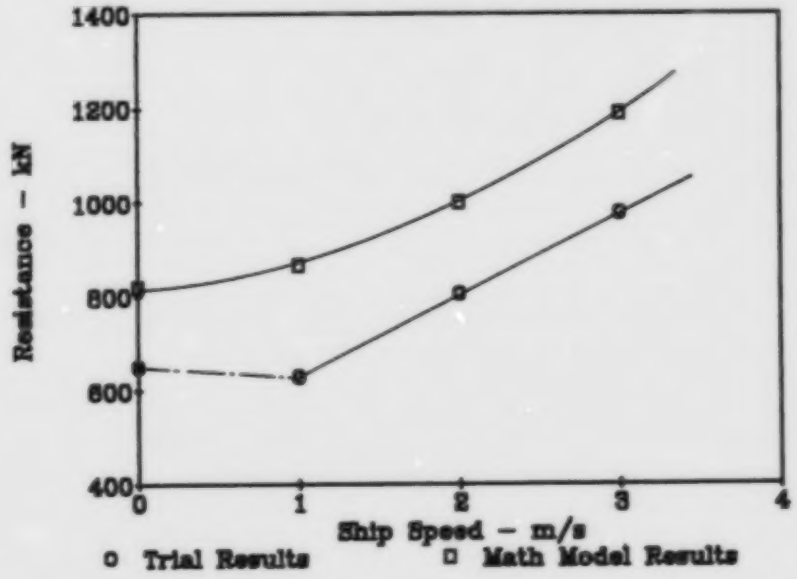
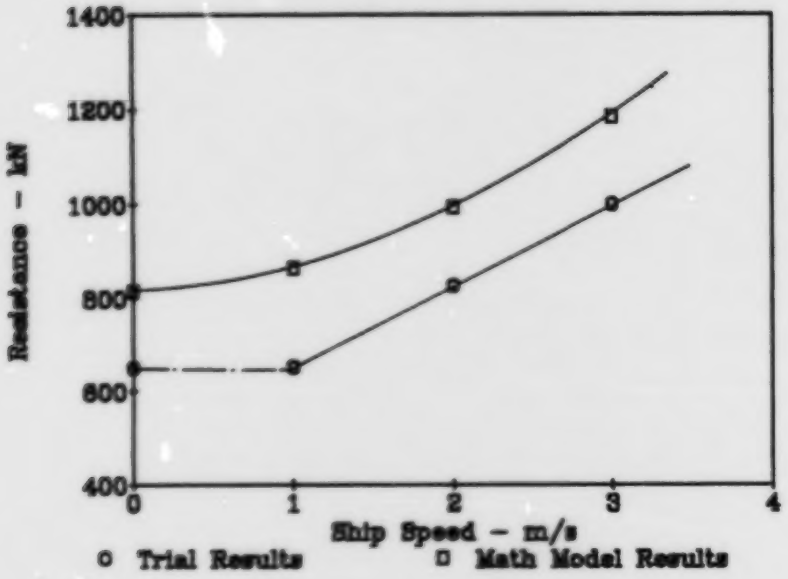


Figure 12
Resistance vs Ship Speed
Condition 2
Ice flexural strength: 670 kPa



Both these plots show the resistance curves to be essentially parallel with the math model predictions significantly higher by an average factor of approximately 1.25 for both conditions.

To check the reliability of the math model when applied to this hull form without strakes, the program was run using full scale data obtained from the PAPA trials for the Type 1100 vessel CCGS "Anne Harvey" (4) a sister ship to the test vessel. The results of these trials are summarized in Table 7. During these icebreaking trials the vessel was operating at a mean draft of 5.44 m with a static trim by the stern of 0.48 m.

Table 7

CCGS Anne Harvey - PAPA Trials		
Level Ice Test Data Measurements		
Ice Flexural Strength : 200 kPa		
Ice Thickness : 0.53 m		
Test ID	Ship Speed	Resistance
	m/s	kN
008	0.72	150
009	1.62	206
010	2.98	243
011	4.42	467
012	1.54	209
013	1.57	185
014	3.34	327
015	3.52	534
022	0.50	156
023	1.26	197
024	2.95	345
025	3.70	519

Hull geometry was lifted from the lines plan for the vessel at the trial draft and trim and the "Carter" model run to determine predicted level ice resistance, the results of which are included as Appendix C and summarized in Table 8.

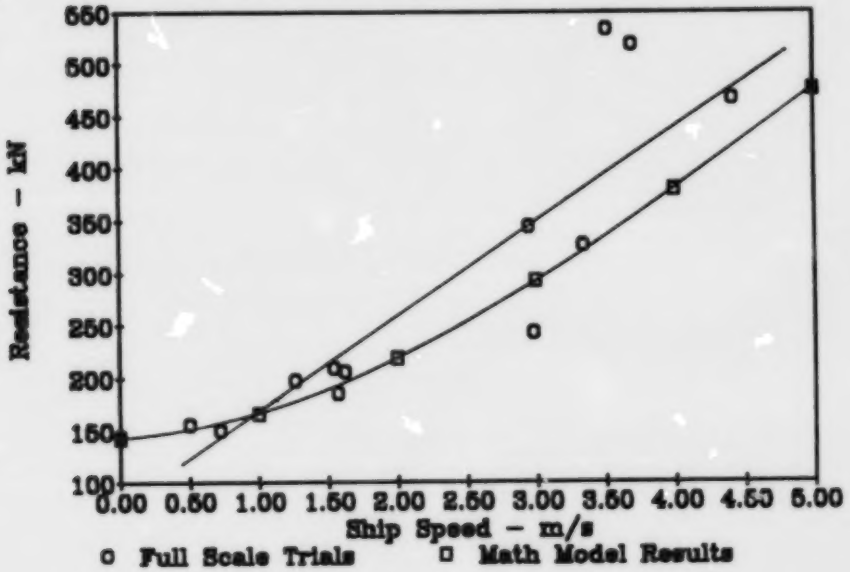
Table 8

MATH MODEL RESULTS				
CCGS Anne Harvey				
Level Ice Resistance (kN)				
Ice Flexural Strength : 200 kPa				
Ship Speed	Ice Thickness - m			
m/s	0.00	0.43	0.53	0.63
0	0	107	143	183
1	5	126	166	209
2	13	171	219	271
3	29	233	293	356
4	51	307	380	457
5	79	388	475	567

A plot of the predicted resistance and full scale results on a base of ship speed is presented in Fig 13.

The correlation of these results can be seen to be very good.

Figure 13
CCGS Anne Harvey
Resistance vs Ship Speed
Ice flexural strength: 200 kPa



The ice flexural strength for the trials of the CCGS "Sir Wilfred Laurier" was calculated as a function of the brine volume which for sea ice is, in turn, a function of temperature and salinity.

Ice strength calculations using this method have been proposed by various authorities, however, in all cases the strength index is related to "sea" ice.

The Saguenay River water is brackish with a relatively low salinity content.

Reference (5), page 6, states, in relation to flexural strength calculations based upon brine volume, that "the theory should be used with much caution in the case of brackish ice".

To analyze the effect on the correlation of full scale with math model results for CCGS "Sir Wilfrid Laurier" with reduced ice strength the model was run again using a flexural ice strength of 500 kPa, this being an average of actual cantilever beam strengths measured in the Saguenay River (6).

Comparison of the results with full scale measurements are indicated in Figs. 14 and 15 for Conditions 1 and 2 respectively.

Figure 14
Resistance vs Ship Speed
Condition 1
Ice flexural strength: 500 kPa

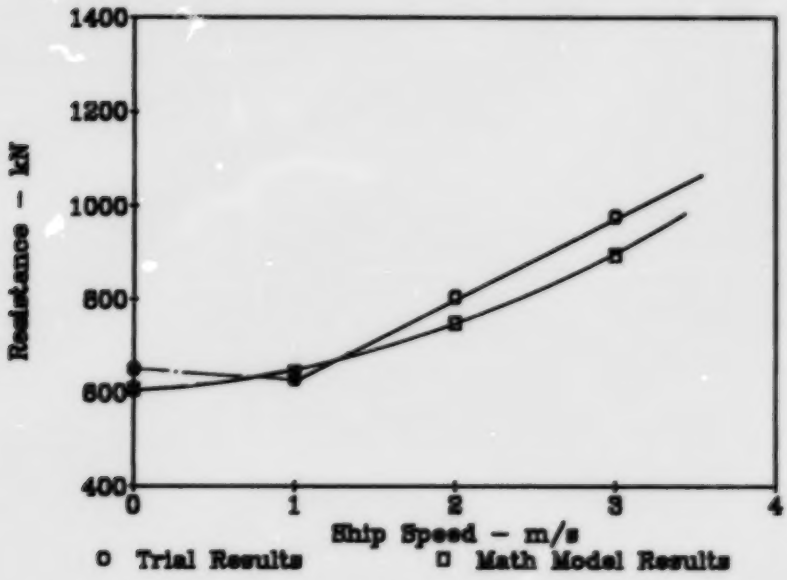
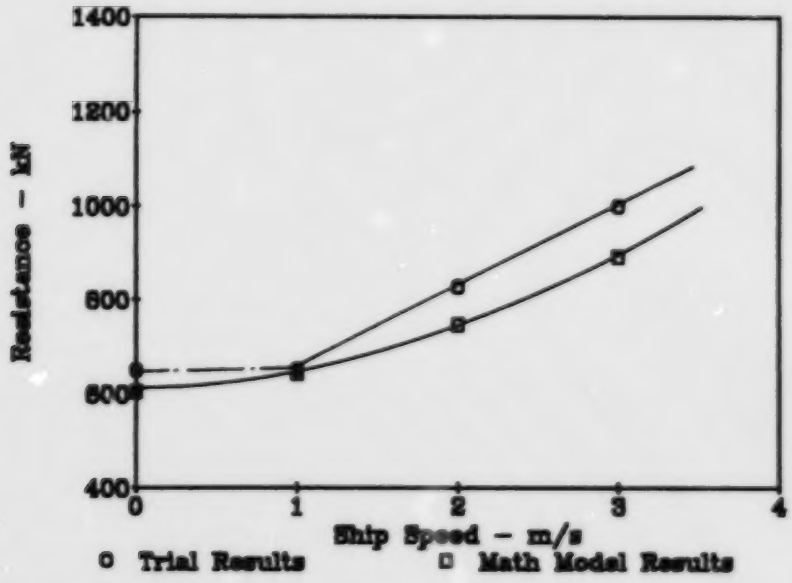


Figure 15
Resistance vs Ship Speed
Condition 2
Ice flexural strength: 500kPa



As can be seen there is good correlation between predicted and full scale results using the reduced ice flexural strength.

Since the math model shows good correlation with full scale results for the CCGS "Anne Harvey" without strakes it is suggested that the estimated ice flexural strength for the subject Saguenay River trials is suspect.

From Figure 10 "Selected Data" full-scale trial results indicate a reduction in icebreaking resistance in Condition 1 over Condition 2 of approximately 3.5% at 2 knots (1 m/s) which indicates that increased immersion of the strakes reduces icebreaking resistance.

However, since no full-scale data exists for the test ship without strakes in similar ice conditions no positive conclusions can be drawn from the Saguenay River trials as to the actual reduction in resistance as a result of the strake application.

5. Conclusions

The purpose of the full-scale trials of the vessel CCGS "Sir Wilfred Laurier" was to determine the effect on level icebreaking resistance with the fitting of strakes and to compare the results with those predicted from a math model as developed by Dr.D.Carter.

From the full scale results and observations made during the test program the following conclusions may be drawn:

1. The math model predictions for reduced icebreaking resistance of 15.3% for Condition 1 and 11.5% for Condition 2 as a result of strake application cannot be verified from the present data principally due to doubt as to actual flexural strength of the ice in the test area.

2. Trial results and observations do suggest that deeper strake immersion reduces icebreaking resistance.

3. Virtual permanent trim by the stern during icebreaking substantially reduced the strakes/ice contact hence the effectiveness of the strakes.

4. Strakes/ice contact was also reduced by the relatively large cusp size of the broken ice pieces, typically formed by vessels with shallow flare angles at the bow, which tended to be deflected down and under the strakes.

5. Although the strakes were positioned at the optimum location as determined from the math model, it was observed during the trials that crushing of the ice occurred ahead of the strakes. The strakes would have been far more effective had they been positioned further forward and lower on the hull in this observed crushing area.

6. The strakes were effective in clearing ice (and snow) thus reducing hull/ice contact along the sides of the vessel.

6. Recommendations

It is recommended that additional full scale tests be carried out to verify the effectiveness of the strakes as applied to the CCGS "Sir Wilfred Laurier" as follows:

1. Retest the vessel in ice of which the flexural strength is a known factor (carry out cantilever beam tests during trials) and at the "design" draft by ensuring sufficient deadweight is available to maximize strake immersion.

2. Since ice crushing was observed ahead of the strakes it is further recommended that two (2) additional strakes, one (1) each side, be fitted at this location and the vessel tested with both existing and "new" strakes installed. These additional strakes would be smaller than those existing and would not be required to be extended to the full beam merely acting as "first" contact to prevent local crushing. It is also considered that these additional strakes may be installed with the vessel afloat alongside thus minimizing installation costs.

7. References

1. "Model tests of the Louis S. St. Laurent original bow fitted with strakes", Dr.D.Carter, TP# 9356E, July 1988.

2. "Handbook of Formulas for Stress and Strain", Griffel.

3. "Full Scale Trails of the CCGS 'Sir Wilfred Laurier' fitted with Strakes," Fleet Technology Limited, TP# 10554E, September 1990.

4. "Type 1100 PAPA Trials - CCGS 'Anne Harvey'," Wartsila Marine Inc., March 1989.

5. "Crystallographic Analysis and Theoretical Flexural Strength of River Ice," Report T6, Michel and Ramseier, 1969.

6. "Resistance 'In Situ' de la glace en flexion, Baie de Ha! Ha!, Riviere Saguenay," Report T5, Michel and Drouin, March 1969.

7. "Hydrodynamics in Ship Design," Volume II, Saunders, SNAME.

Appendix A

Strakes

Math Model Study

KRISTI MARITIME Inc.
P.O. Box 1153, Pointe Claire
Quebec, Canada, H9S 4H9

- MATH MODEL STUDY -

STRAKES APPLICATION ON THE CCGS SIR WILFRID LAURIER

prepared by

Donald Carter,P.Eng.,D.Sc.
DONALD CARTER & ASS.,
CONSULTANTS
1281 Bishop, Ste-Foy,
G1W-3E4
Tel.:(418) 656-0690

10 May 1989

TABLE OF CONTENTS

	Page
1.: INTRODUCTION	1
2.: SHIP DESCRIPTION	1
3.: STRAKES ARRANGEMENTS	2
4.: STRAKES SIZE	4
5.: STRAKES OPENING ANGLE	4
6.: CONCLUSIONS	5

LIST OF FIGURES

FIGURE 1.: Ice Resistance Distribution along the Forebody Section with no Strakes	7
Figure 2.: Strakes Arrangements Located between Frame 138 and Frame 148	8
Figure 3.: Strakes Arrangements Located between Frame 138 and Frame 154	9
Figure 4.: Ice Resistance Distribution along the Forebody Section With Strakes.	10

1.: INTRODUCTION

The following report documents the results of a math model study on the project: "Strakes Application on a Canadian Coast Guard Vessel". On behalf of KRISTI MARITIME Inc., the analytical assessment was made using a computer program previously developed by Donald Carter.

Preliminary studies have indicated that a substantial improvement in icebreaking efficiency may be achieved by fitting strakes on the shoulder areas of the CCGS Laurier.

The purpose of the math model study was to provide an analytical assessment of the effect of strakes position, slope, and shape on the total ice resistance.

2.: SHIP DESCRIPTION

The forebody waterplane data, which has been faired and checked by KRISTI MARITIME Inc., is listed in TABLE 1.

TABLE 1

CCGS Sir Wilfrid Laurier
Hull Form Data Sheet
Waterline 6 metres - Even Keel
Forebody Waterplane Geometry

Bow Run m	1/2 Breadth m	ALPHA (°)	BETA (°)	GAMMA (°)
0,0	8,10	0,0	0,0	0,0
2,3	8,05	2,5	1,6	57,4
4,6	7,89	5,9	5,1	49,2
6,9	7,56	10,2	10,6	44,0
9,2	7,04	15,6	17,8	41,0
11,5	6,27	20,9	25,0	39,3
13,8	5,26	25,4	32,4	36,8
16,1	4,08	28,8	39,3	33,9
18,4	2,80	29,9	45,0	29,9
20,7	1,45	30,0	48,5	27,0
23,0	0,10	30,0	49,8	26,0

Note.: Bow Run "0" corresponds with Station 7 on Lines Plan.

The ice forces acting against the ship hull were first calculated by the the Carter's math model for the situation with no strakes fitted onto the hull. Throughout the study, the following ice properties were used as typical values:

Ice Flexural Strength	:	500 kPa
Ice Compressive Strength	:	1 625 kPa
Ratio Elastic Modulus / Strength	:	5 000
Ice Thickness	:	1 m
Coefficient of Friction	:	0,1

Figure 1 shows the ice resistance distribution along the forebody section with no strakes. The figure speaks for itself. The bow breaks ice quite effectively with its forward part where high flare angles develop a downward force on the ice sufficiently large to cause failure by bending.

However, further aft, the flare reduces to zero as it approaches parallel mid-body, as a result significant crushing occurs at the shoulders of the vessel.

By fitting strakes on the bow shoulder area, it is believed that the ice will be deflected down the hull as the ship advances, which should result in icebreaking and not ice crushing as laboratory and field tests have shown that an ice cover is much more easily broken in bending by a vertical force than in crushing by an in-plane horizontal force.

3.: STRAKES ARRANGEMENTS

Five practical strakes arrangements have been suggested by John E. Carter of KRISTI MARITIME Inc. after a close examination of the hull form and structure. Figure 2 shows three strakes arrangements, located between frame 134 and frame 138, with respective slope of 10°, 15°, and 19,93°.

Figure 3 shows two additional strakes arrangements with the forward extremity located at the watertight bulkhead, frame 152. The strakes inclination are then 10° and 14,52°.

The math model results for the five arrangements are given in the following table.

TABLE 2

MATH MODEL RESULTS

STRAKES ARRANGEMENT		R_1 (kN)	R_2 (kN)	R_t (kN)	ΔR_t (%)
WITH NO STRAKES		1727	----	1727	0%
AS PER FIGURE 2					
Inclination	10°	582	626	1208	-30%
Inclination	15°	552	610	1162	-33%
Inclination	19,93°	539	606	1145	-34%
AS PER FIGURE 3					
Inclination	10°	510	631	1141	-34%
Inclination	14,52°	491	620	1111	-35%

Note: R_1: Average Ice Resistance Acting against Bare Hull;
R_2: Average Ice Resistance Acting against Strakes;
R_t: Total Ice Resistance;
ΔR_t: Variation of Total Ice Resistance (%).

It is our opinion that a difference of 1 or 2% in calculated icebreaking improvement is not worth locating the strakes in the buoy hook-up area, considering the potential problems they may cause to normal operations.

The arrangements with strakes slope of 15° and 19,93°, as shown on Figure 2, are more or less equivalent from an icebreaking efficiency point of view and the final choice should be made by considering the configuration that produces the smallest interference with the wave profile along the bow.

Figure 4 shows the ice resistance distribution along the forebody section associated with the 15° or 19,93° slope. It is clearly shown that the bow part forward of the strakes is already very efficient and nothing will be gained by fitting additional strakes onto that hull part.

4.: STRAKES SIZE

The math model does not allow to bring out a significant difference between using, on each side of the bow, two (2) 200-mm strakes in place of one (1) 400-mm strake.

However, model test results have clearly evidenced that, after the ice cover has been deflected, cracked, and broken as it came into contact with a strake, few ice pieces were prevented by a lower strake from following a smooth path down along the bare hull sides.

It is our opinion that the ice submerging component would be slightly increased if two close-spaced strakes were fitted on the bow shoulder areas.

5.: STRAKES OPENING ANGLE

The effect of the strakes opening angle, ψ, was studied for the 15° and 19,93° configurations shown on Figure 2.

The results are listed in the following TABLE.

STRAKES CROSS-SECTION

TABLE 3

INFLUENCE OF STRAKES OPENING ANGLE

OPENING ANGLE	STRAKES CONFIGURATIONS	
ψ (degrees)	15°-Slope ΔR(%)	19,93°-Slope ΔR(%)
30°	-15%	-18%
45°	-27%	-29%
60°	-33%	-34%
75°	-33%	-34%
90°	-32%	-33%

The recommended 60° opening angle satisfies simultaneouly high icebreaking efficiency, good structural stability, easy manufacturing, and reduced flow disturbing.

6.: CONCLUSIONS

The following conclusions may be drawn from the math model study of strakes application on the vessel CCGS LAURIER:

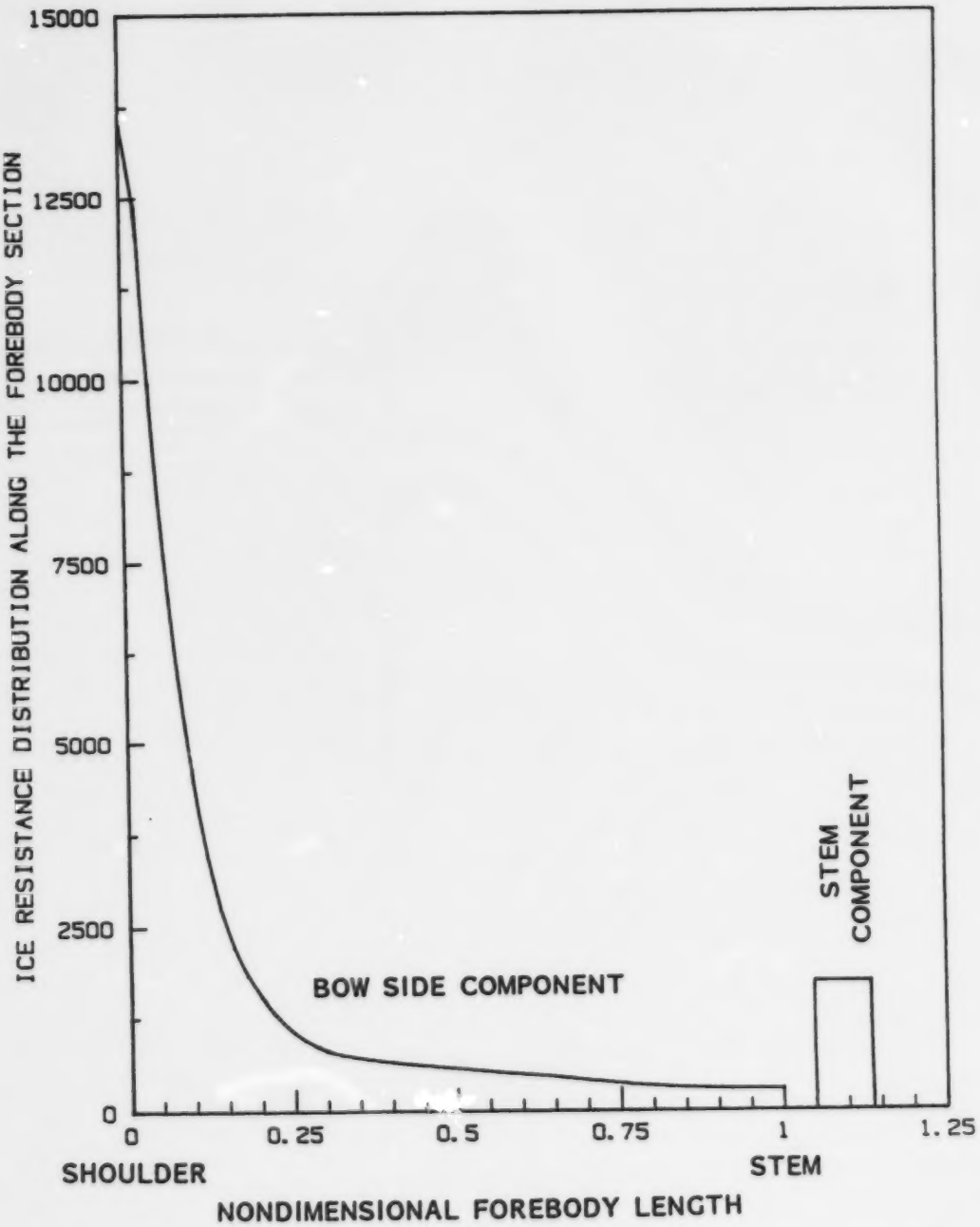
1.: By fitting strakes on the bow shoulder area of CCGS "Sir Wilfrid Laurier", a 30% decrease in level ice resistance may be achieved.

2.: From an icebreaking efficiency point of view, two strakes configurations located between frame 134 and frame 138, with respective slope of 15° and 19,93° are almost equivalent. The final choice should be based on hydrodynamic considerations.

3.: The optimum strake opening angle is 60°.

4.: One 400-mm strake on each bow side should be preferred to two 200-mm strakes which would slightly increase the ice submergence component.

THIS PAGE INTENTIONALLY LEFT BLANK



ICE RESISTANCE DISTRIBUTION ALONG THE FOREBODY SECTION WITH NO STRAKES.

FIGURE 1

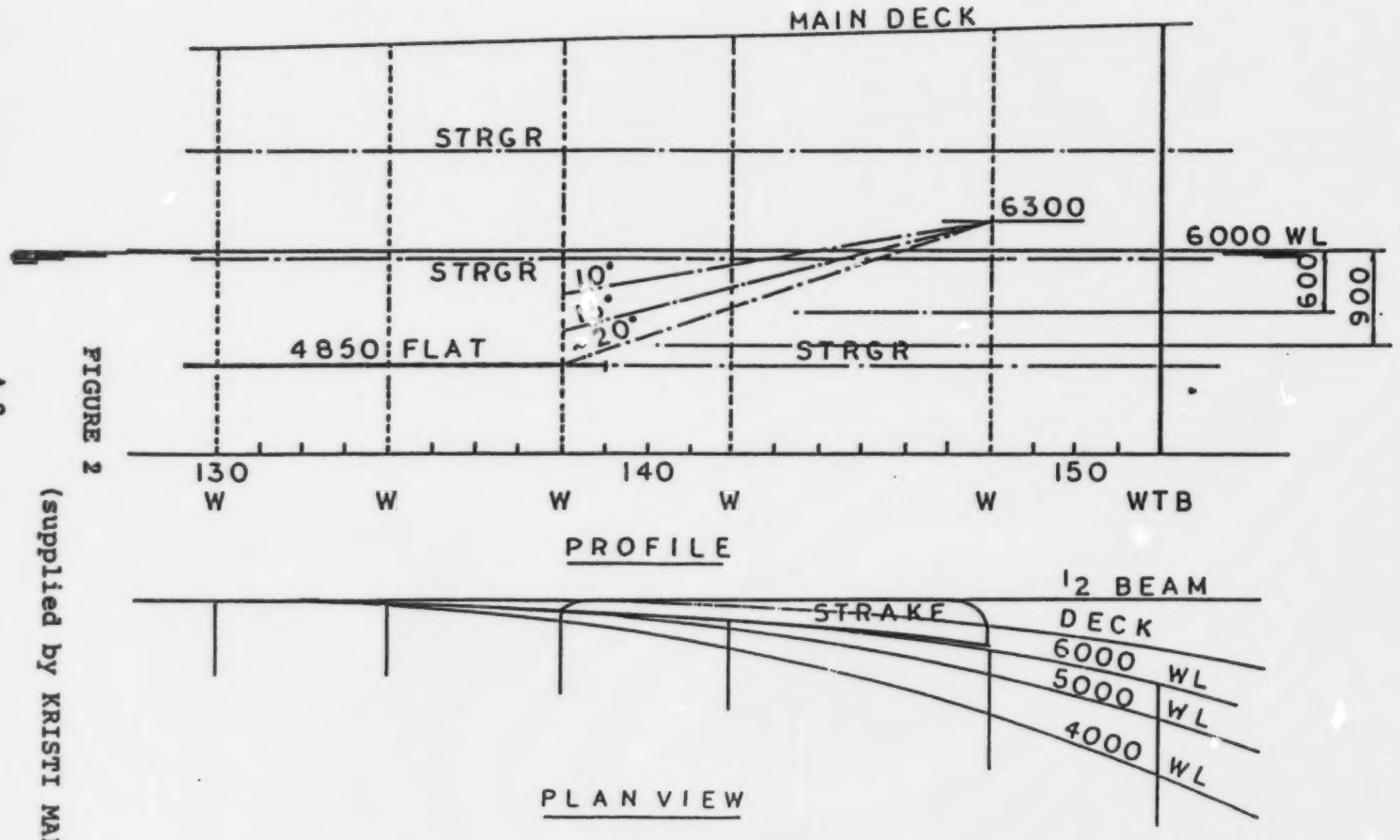


FIGURE 2

(supplied by KRISTI MARITIME Inc.)

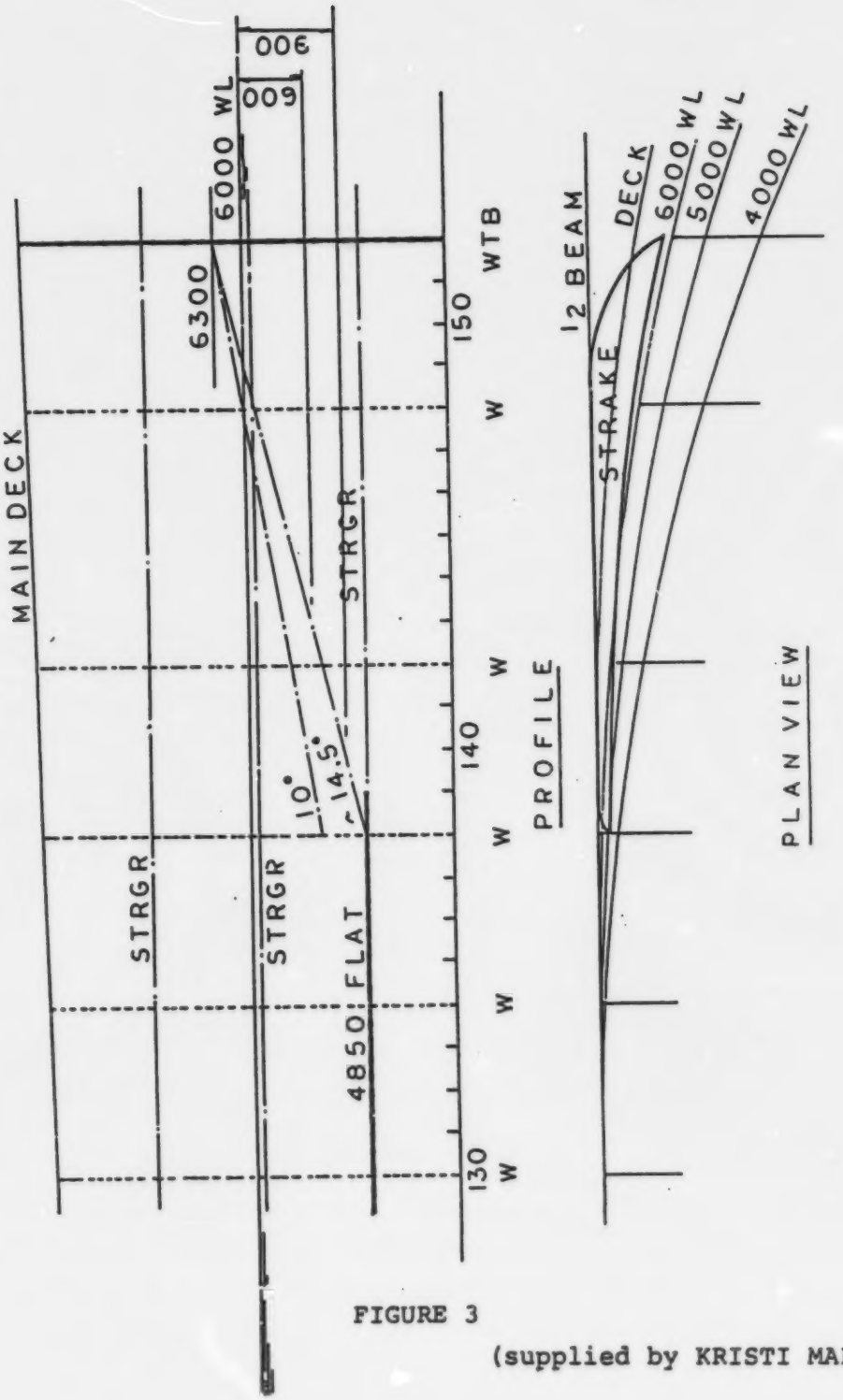
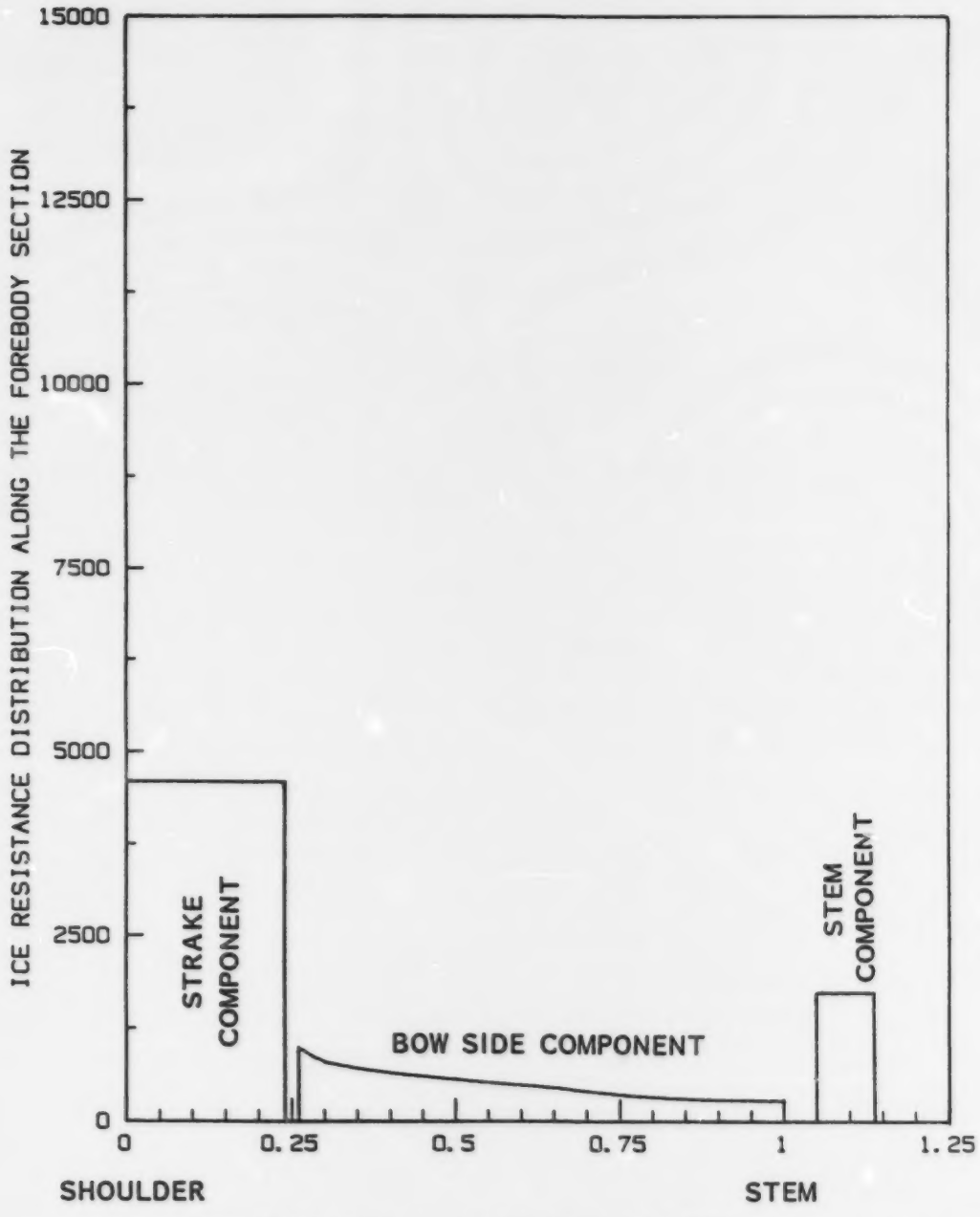


FIGURE 3

(supplied by KRISTI MARITIME Inc.)



ICE RESISTANCE DISTRIBUTION ALONG THE FOREBODY SECTION WITH STRAKES.

FIGURE 4

Appendix B

Strakes

Structural Arrangement

NOTES:

1. PRIOR TO INSTALLATION HULL SURFACE IN WAY OF STRAKES TO BE CLEANED TO BARE METAL AND BUTTS AND SEAMS GROUND SMOOTH AND FLUSH IN WAY OF DOUBLER.
2. BUTTS IN DOUBLER TO BE WELDED PRIOR TO ATTACHMENT TO SHELL. AND SHALL BE KEPT CLEAR OF SHELL SEAMS AND BUTTS.
3. WELDING SHALL BE IN ACCORDANCE WITH REQUIREMENTS OF CANADIAN COAST GUARD - FLEET SYSTEMS: WELDING SPECIFICATION FOR FERROUS MATERIALS, REVISION # 4.
4. SEE ALSO KRISTI MARITIME INC SPECIFICATION 8901

MATERIALS:

DOUBLER PLATE	HTS LLOYDS GR. EH 36
TOP & BOTTOM PLATES	LLOYDS GR E
BRACKETS & BACKING BARS	LLOYDS GR E
SOLID ROUND NOSE BAR	ASTM GR A 36
INTERNAL STIFFENING	LLOYDS GR E.

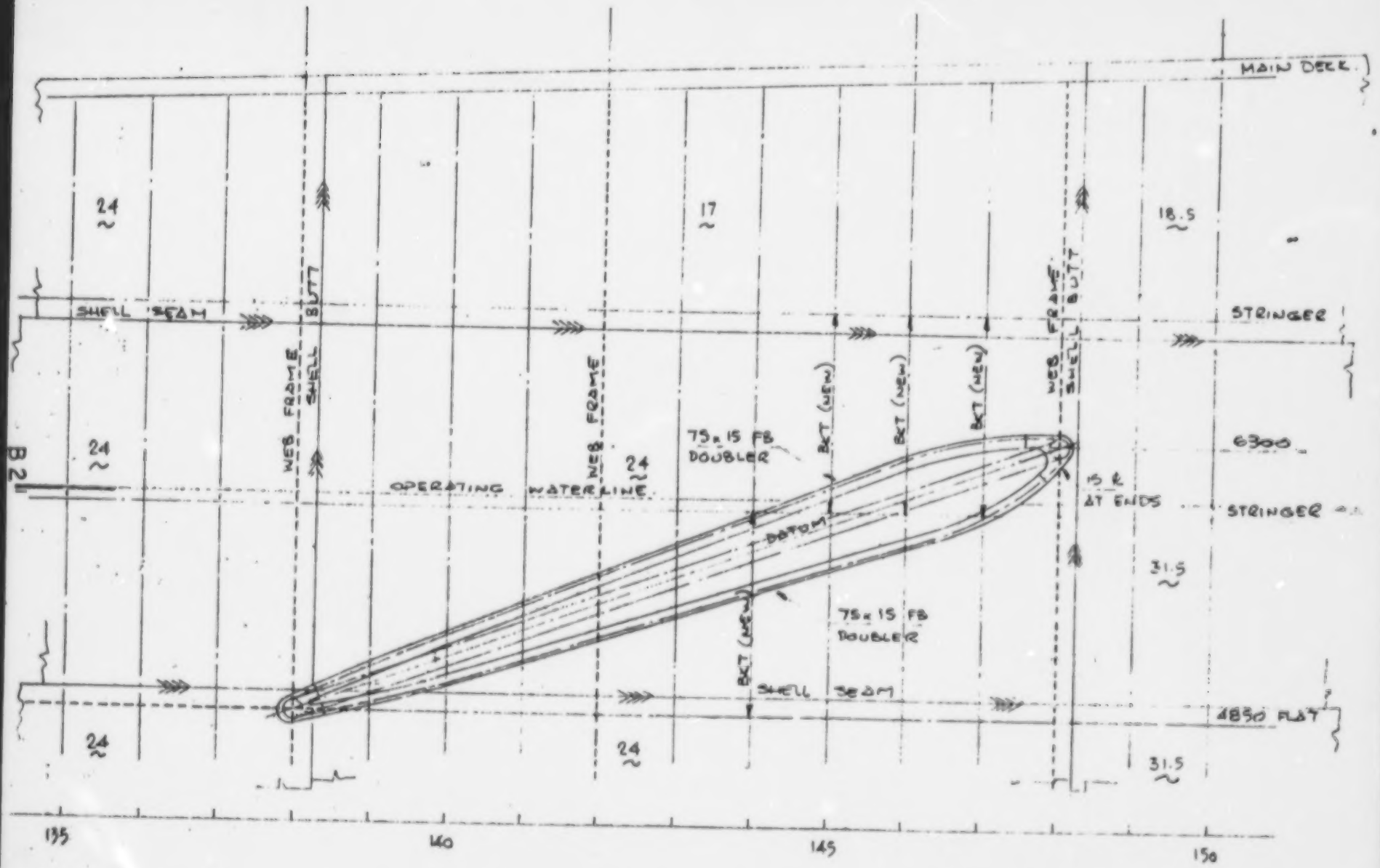
kristi maritime
NAVAL ARCHITECTS
POINTE CLAIRE VILLAGE P.Q.

CLIENT TRANSPORT DEVELOPMENT CENTRE

PROJECT STRAKES

TITLE STRUCTURAL ARRANGEMENT

DRAWN JEGT	DATE 12 Sept. 1989	SCALE 1:20 AND AS SHOWN.
DWG. NO. 8901-200-01	REV. 3	SHT. 1 OF 1

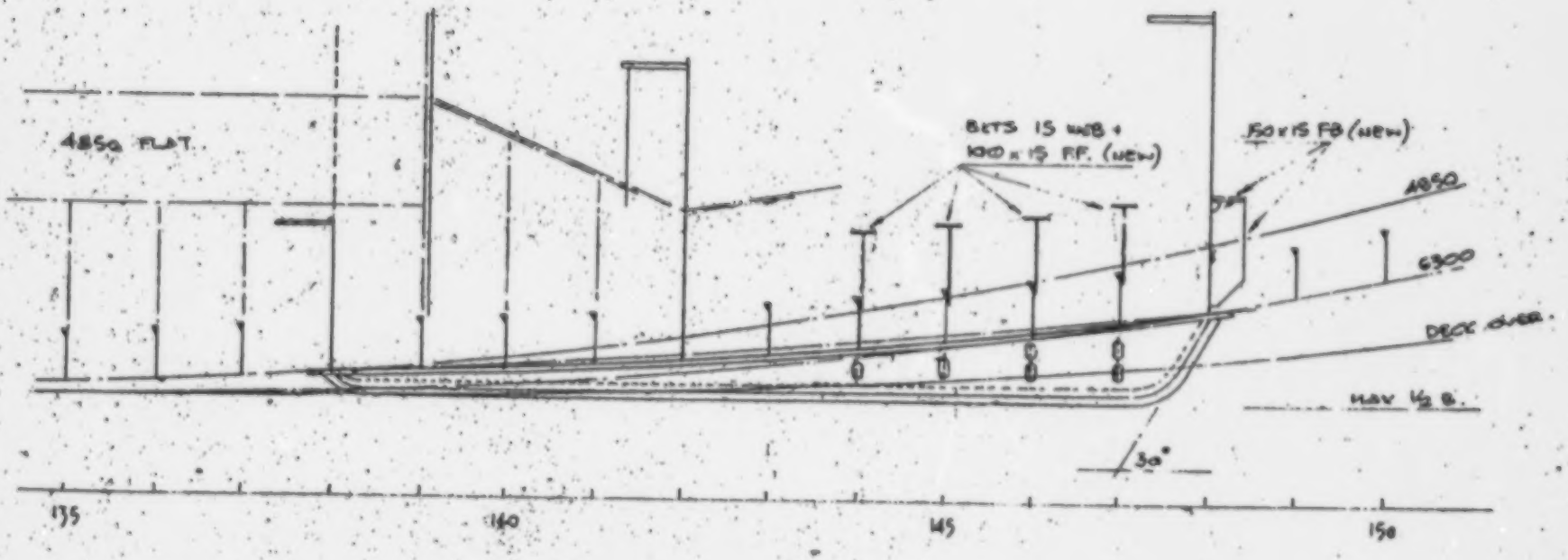


PROFILE

STARBOARD SIDE

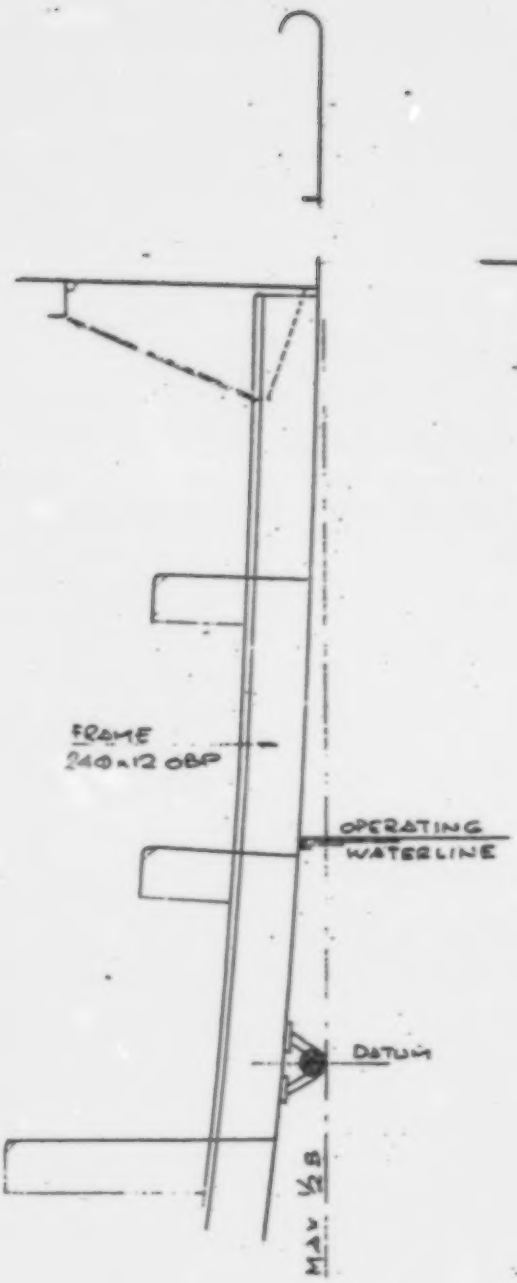
LOOKING TO PORT

— — 400 FR SPACING — —

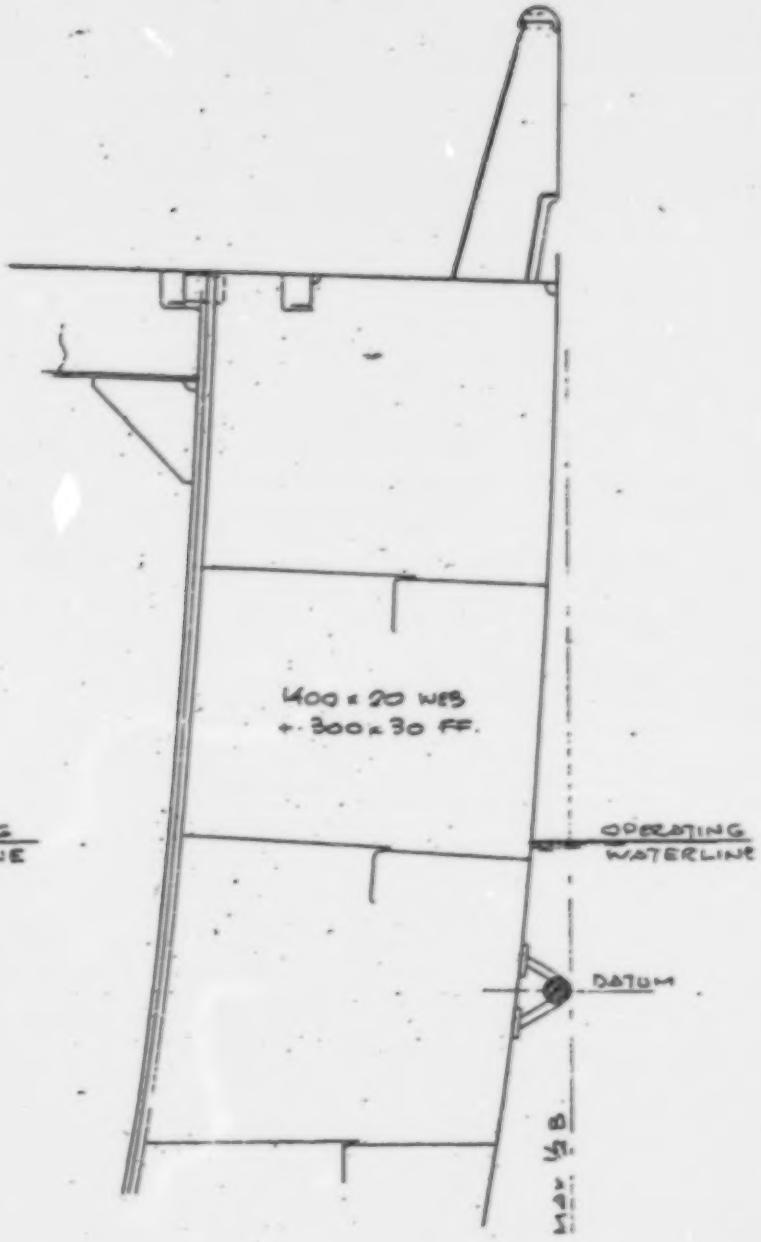

4850 FLAT.
BETS 15 WEB +
100 x 15 FF. (NEW)
150 x 15 FB (NEW)
4850
6300
DECK OVER.
MAY ½ B.
30°
135
140
145
150

PLAN VIEW

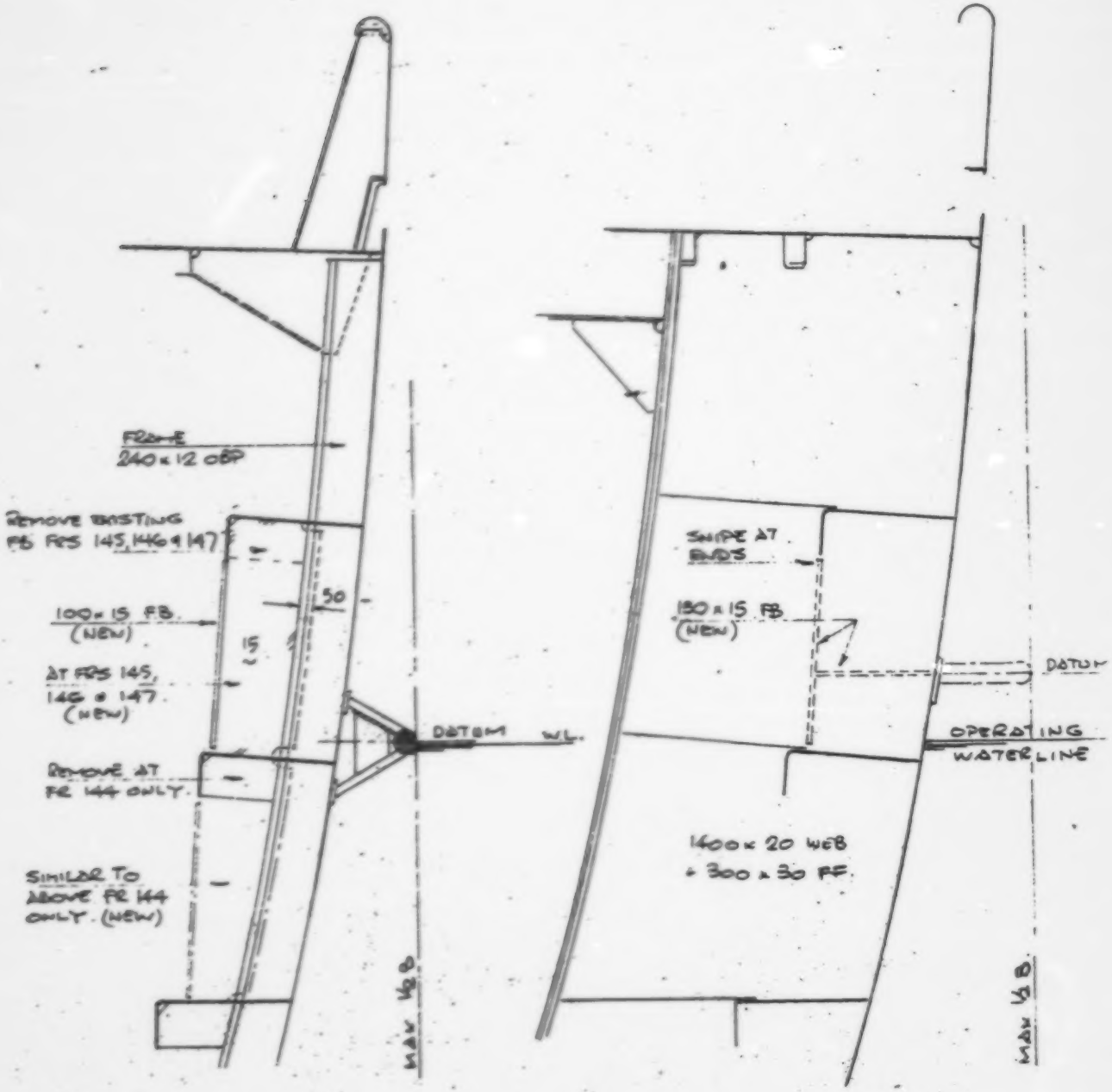
B3



SECTION FR 140

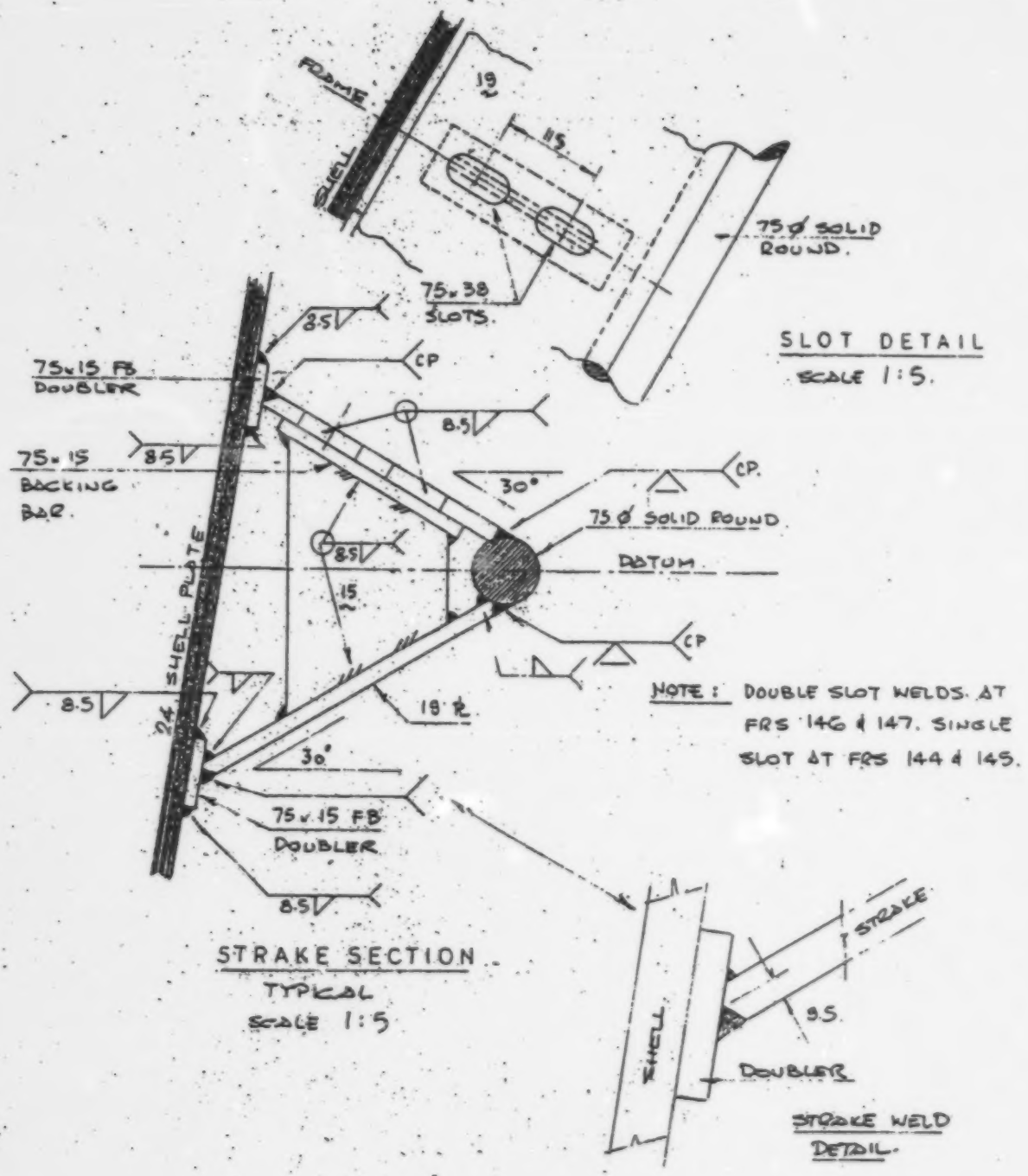


SECTION FR 142



SECTION FR 146

SECTION FR 148


FRAME
SHELL
19
115
75 Ø SOLID ROUND.
75 x 38 SLOTS.
SLOT DETAIL
SCALE 1:5.
75 x 15 FB DOUBLER
8.5
CP
75 x 15 BACKING BAR.
30°
75 Ø SOLID ROUND
DATUM
15
SHELL PLATE
24
18 ℄
NOTE: DOUBLE SLOT WELDS AT FRS 146 & 147. SINGLE SLOT AT FRS 144 & 145.
STRAKE SECTION
TYPICAL
SCALE 1:5
STRAKE
9.5
DOUBLER
STRAKE WELD DETAIL.

Appendix C

CCGS Anne Harvey

Carter Model Study

CCGS ANNE HARVEY

CONTINUOUS ICEBREAKING MODE

LEVEL ICE RESISTANCE AS PREDICTED

BY CARTER'S MODEL

VESSEL'S PRINCIPAL PARTICULARS

LENGTH (B.P)...:	75.0 M.
FOREBODY LENGTH...:	21.3 M.
BREADTH...:	16.2 M.
DRAUGHT...:	5.4 M.
DISPLACEMENT...:	4227.3 CUBIC M.
WATERLINE ENTRANCE ANGLE...:	31.1 DEGREES
PARALLEL MID-BODY FLARE ANGLE.:	0.0 DEGREES
STEM ANGLE...:	26.3 DEGREES
SHAFT HORSEPOWER...:	7000.0 H.P.
MAX. SPEED IN OPEN WATER*...:	7.7 M/S
BOLLARD THRUST...:	731.5 KN

*AS ESTIMATED BY THE PROGRAM

ICE COVER CHARACTERISTICS

ICE FLEXURAL STRENGTH...:	200.0 KPA
HULL/ICE FRICTION COEFFICIENT.:	0.06

NO SNOW COVER

- TABLE 1 -

EFFICIENCY INDICES VERSUS ICE THICKNESS
(FRICTION COEFFICIENT = 0.06)

ICE THICKNESS M.	0.43	0.53	0.63
FORCES(Z)/FORCES(X) ICE BREAKING INDEX	0.85	0.86	0.86
FORCES(Y)/FORCES(X) ICE MOVING INDEX	5.83	5.80	5.77

TABLE - 2 -

POSITION OF THE RESULTANT VERTICAL FORCE (M.)

ICE THICKNESS M.	0.43	0.53	0.63
DISTANCE (X)	12.65	12.82	12.97

TABLE - 3 -

PREDICTED LEVEL ICE RESISTANCE (KN)
(OPEN WATER RESISTANCE NOT INCLUDED.)

SHIP SPEED (M/S)	ICE THICKNESS (M.) 0.43	0.53	0.63
0.	107.	143.	183.
2.	158.	206.	258.
4.	256.	329.	406.
6.	365.	467.	574.
8.	477.	609.	747.
10.	591.	754.	924.

TABLE - 4 -

TOTAL LEVEL ICE RESISTANCE (KN)
(OPEN WATER RESISTANCE INCLUDED)

SHIP SPEED (M/S)	FULL POWER THRUST	ICE THICKNESS (M.) 0.00	0.43	0.53	0.63
0.00	732.	0.	107.	143.	183.
1.00	660.	5.	126.	166.	209.
2.00	589.	13.	171.	219.	271.
3.00	518.	29.	233.	293.	356.
4.00	447.	51.	307.	380.	457.
5.00	376.	79.	388.	475.	567.
6.00	305.	112.	476.	578.	685.
7.00	233.	150.	571.	688.	810.
7.72	182.	182.	643.	771.	905.

TABLE - 5 -

MAXIMUM SHIP SPEED (M/S)
VERSUS ICE THICKNESS (M.)

0.00	7.72
0.25	5.98
0.29	5.75

TABLE - 6 -

MAXIMUM EXTRACTION FORCE (KN)
VERSUS ICE THICKNESS (M.)

0.00	0.00
1.00	124.45
1.50	214.93
2.00	309.38
2.50	412.35
3.00	523.23
3.50	641.62
4.00	765.72

TABLE - 7 -
MEAN FORCE PER UNIT LENGTH (KN/M)
ACTING ALONG BOW SIDES AT CREEPING SPEED.*

A.: NORMAL COMPONENT PER UNIT LENGTH.

X/L	ICE THICKNESS (M.) 0.43	0.53	0.63
0.0	175.89	244.20	320.81
0.2	14.25	18.80	23.67
0.4	4.56	6.03	7.61
0.6	2.80	3.69	4.64
0.8	2.29	2.97	3.69
1.0	2.30	2.98	3.70
1.0	16.62	25.25	35.68

B.: RESULTANT FORCE PER UNIT LENGTH

X/L	ICE THICKNESS (M.) 0.43	0.53	0.63
0.0	176.21	244.64	321.39
0.2	14.28	18.83	23.71
0.4	4.57	6.04	7.63
0.6	2.81	3.70	4.65
0.8	2.29	2.98	3.69
1.0	2.30	2.99	3.71
1.0	16.65	25.30	35.74

* FOR OTHER VALUES OF SHIP SPEED, MULTIPLY THE FORCES PER UNIT LENGTH GIVEN IN TABLE 7 AND TABLE 9 BY THE CORRESPONDING SPEED AMPLIFICATION FACTOR GIVEN IN TABLE 8.

TABLE -8 -
STRESS AMPLIFICATION FACTOR VERSUS SHIP SPEED (M/S).

SPEED (M/S).	ICE THICKNESS (M.) 0.43	0.53	0.63
0.0	1.00	1.00	1.00
2.0	1.48	1.44	1.41
4.0	2.40	2.30	2.22
6.0	3.42	3.26	3.13
8.0	4.47	4.25	4.08
10.0	5.53	5.26	5.05

TABLE - 9 -

RECTANGULAR COMPONENTS OF THE MEAN FORCE BY UNIT LENGTH (KN/M) ACTING ALONG BOW SIDES AT CREEPING SPEED.*

A.:LONGITUDINAL COMPONENT, X-FORCES. (KN/M)

X/L	ICE THICKNESS (M.) 0.43	0.53	0.63
0.0	15.96	22.16	29.12
0.2	2.34	3.09	3.89
0.4	1.51	1.99	2.52
0.6	1.17	1.54	1.94
0.8	0.95	1.24	1.53
1.0	0.95	1.24	1.54
X-FORCES (KN)			
BOW X-FORCES	100.12	132.90	168.16
STEM X-FORCES	9.05	13.75	19.43
TOTAL X-FORCES	109.17	146.65	187.59

B.:TRANSVERSAL COMPONENT, Y-FORCES. (KN/M)

X/L	ICE THICKNESS (M.) 0.43	0.53	0.63
0.0	175.57	243.75	320.22
0.2	13.97	18.43	23.21
0.4	3.92	5.19	6.55
0.6	1.86	2.45	3.08
0.8	1.33	1.73	2.15
1.0	1.34	1.74	2.16
Y-FORCES (KN)			
BOW Y-FORCES	648.41	867.32	1104.31
STEM Y-FORCES	0.00	0.00	0.00
TOTAL Y-FORCES	648.41	867.32	1104.31

C.:VERTICAL COMPONENT, Z-FORCES. (KN/M)

X/L	ICE THICKNESS (M.) 0.43	0.53	0.63
0.0	0.00	0.00	0.00
0.2	1.77	2.33	2.93
0.4	1.80	2.38	3.00
0.6	1.75	2.30	2.89
0.8	1.60	2.08	2.58
1.0	1.61	2.09	2.60
Z-FORCES (KN)			
BOW Z-FORCES	77.31	101.51	127.29
STEM Z-FORCES	13.98	21.23	30.00
TOTAL Z-FORCES	91.29	122.75	157.29